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This is a report on measurement and analysis of velocity profiles in bounded shear flows in a laboratory flume with various flow intensities and depths and two very different roughness magnitudes and types.

A new computational procedure was developed to define a virtual origin and successfully applied as part of a larger program named VELMEAS; this computational program was developed in the course of this research as an accurate and expandable tool for analyzing boundary layer flows; it is also suitable for collecting and analyzing any set of data samples produced in voltage form. Basic statistical and regression analysis are performed efficiently, and the boundary layer analysis is documented in graphic and table form. Many graphs illustrating boundary layer phenomena are included in this report. The source FORTRAN code is also included.

The virtual-origin search reveals the relative thickness of the logarithmic and wake-regions. The magnitude of various relevant parameters, including the Karman coefficient, the intercept and the wake strength coefficient, is computed as functions of different virtual origin estimates. The procedure would give better results with more sophisticated instrumentation than the simple total head tube used in this study.

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ABSTRACT

This is a report on measurement and analysis of velocity profiles in bounded shear flows in a laboratory flume with various flow intensities and depths and two very different roughness magnitudes and types.

A new computational procedure was developed to define a virtual origin and succesfully applied as part of a larger program named VELMEAS; this computational program was developed in the course of this research as an accurate and expandable tool for analizing boundary layer flows; it is also suitable for collecting and analyzing any set of data samples produced in voltage form. Basic statistical and regression analysis are performed efficiently, and the boundary layer analysis is documented in graphic and table form. Many graphs illustrating boundary layer phenomena are included in this report. The source FORTRAN code is also included.

The virtual-origin search reveals the relative thickness of the logarithmic and wake-regions. The magnitude of various relevant parameters, including the Karman coefficient, the intercept and the wake strength coefficient, is computed as functions of different virtual origin estimates. The procedure would give better results with more sophisticated instrumentation than the simple total head tube used in this study.

TABLE OF CONTENTS

Page

LIST OF TABLES

<u>**LIST OF FIGURES**</u>

Figure **Page**

Figure **Page**

Figure **Page**

Figure	Page

Figure **Page**

Figure	Page

Figure **Page**

Figure **Page**

Figure	Page

CHAPTER 1

BRIEF ON RESEARCH DONE

1.1. Objectives

This is the final report on a project research entitled "Comprehensive Study of the Karman Coefficient" conducted under a specific cooperative agreement by the USDA National Sedimentation Laboratory and the Center for Computational Hydroscience and Engineering of the School of Engineering, The University of Mississippi.

The program, extending over two years, consisted of basic studies of the velocity profile in bounded shear flow, and included the following research:

a. Measurement of velocity profiles in bounded shear flows of various intensities and depths, over boundaries of two roughness magnitude and type.

b. Determination of a valid definition for the virtual origin of the velocity profile for each of the flow conditions and boundary types investigated.

c. Determination of the relative thicknesses of the logarithmic and wake-region parts of velocity profiles for each of the flow conditions and boundary types investigated.

d. Determination of a valid definition of the Karman coefficient for each of the flow conditions and boundary types investigated.

e. Determination of local skin friction coefficient and Darcy-Weisbach resistance coefficient values for each of the flow conditions and boundary types investigated.

The law of the wall and the velocity defect law have attained customary usage in practical applications requiring vertical distributions of velocities in two-dimensional, fully-developed open-channel flows over smooth and rough beds. However, this extended use has been carried out without detailed verification in many cases. A parallel independent study made with the most accurate available equipment based in Laser Doppler Anemometry (LDA) over smooth beds arrived at the conclusion that "the Karman constant k and the integral constant A are truly universal, having values of k = 0.412 and A = 5.29 irrespective of the Reynolds and Froude number. As the Reynolds number becomes larger, the deviation from the log-law cannot be neglected in the outer region. This deviation can be expressed well by Coles' wake function involving a Reynolds-number dependent parameter <." (Nezu and Rodi, 1986). In the present research much less accurate instrumentation based on a simple Pitot tube has been used. The use of an available Hot-film Anemometer or an LDA equipment was rejected for two reasons. First, no LDA equipment was available. Also LDA is presently not capable of being used with sediments except for very low concentrations. Secondly, the future expansion of this research should include sediment-suspending flows. Hot film probes cannot be used in the presence of sediment because their fragility.

An additional objective was to develop analysis technology ; the course of the investigation and parallel advancements in the field occurring during the two year research made advisable reorienting part of the research efforts towards developing the analysis technology to make feasible a fast, accurate and objective analysis of increasingly larger amounts of information. Hence, an additional objective was informally added to previously listed ones:

f. Developing a computational program capable of providing automatic analysis of all information relevant to the previously listed objectives.

This additional objective, ultimately attained in the form of a computational program named VELMEAS Version 1 (for VELocity MEASurements) proved to be one the most important results of the research. Its use revealed the high sensitivity of results to slight changes in the estimation of the virtual origin of the velocity distribution (where $U = 0$), which can for the first time be precisely provided (if the raw data is accurate enough).

This finding indicates that a new analysis of a vast amount of carefully obtained data obtained in the past, for instance by Nikuradse (1933), if done with the new analytical techniques, may significantly increase understanding of the velocity distribution laws.

1.2 The Laboratory Flume

The experiments were conducted in a recirculating, adjustable-slope flume located at the USDA National Sedimentation Laboratory (Oxford, Mississippi). The flume has an 18 m. channel, 0.6 m. wide and 0.3 m. deep (Figure 1.1), but only small flow depths between 0.06 and 0.10 m were used with different discharges to avoid undesireble wall effects (Nonetheless, a wall-correction method was included in the analysis).

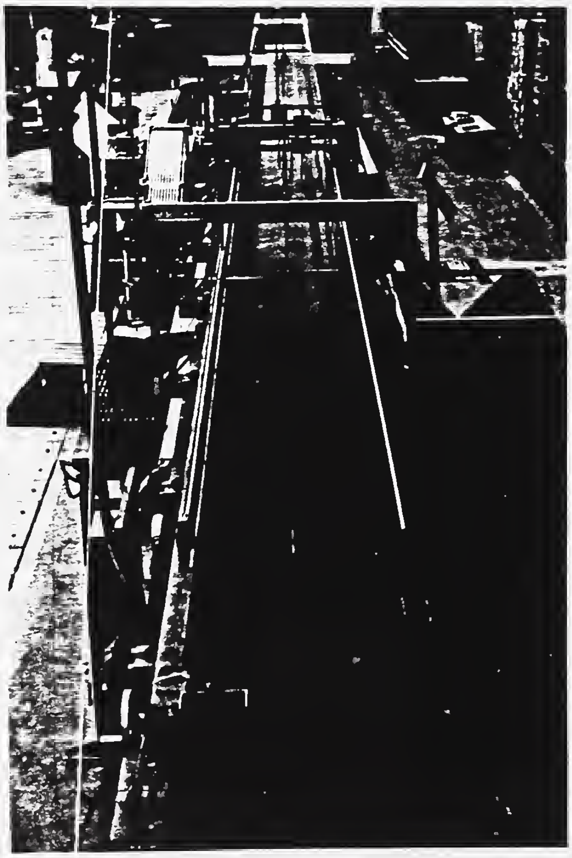


Figure 1.1 : The Laboratory Flume

The channel is constructed of stainless steel, except for two 3 m. long glass windows near the middle section. The flow in the flume is driven by a centrifugal pump regulated by a discharge valve. The flow is measured by a Venturi meter in the recirculation line to the flume channel. A damping basin is located at each end of the channel, and a battery of flow straightening tubes was added in the inflow section to further eliminate secondary flow. A surface-wave breaker was also installed in the inflow section to produce a final steady state regime with almost no perturbations.

The flume is mounted on a central bearing pedestal and four interconnected screw jacks, which provides a system for adjusting the channel slope. Two floor-mounted frames located at approximately one-third points of the flume length supported glass cylinders with a diameter of 100 mm, hydrostatically connected by tubes with corresponding sections of the flume 6096 mm. apart. The water surface in these tubes had a surface free of capillarity effects with remarkably stable elevation, because of the large tube diameter. The difference of elevation in between the two tube water surfaces, measured with point gauges having a precision of 0.3048 mm, was divided by the distance between the two sections to obtain the flow-surface slope with acceptable accuracy. The flume slope was obtained by using other point gauges to measure the instrument rail elevations at the same sections. At the beginning of an experiment, after discharge was set, the flume slope was adjusted and the water slope was measured until uniform flow was produced at the velocity profile measuring section. The velocity measuring probe was positioned with accuracy of 0.01 mm by means of a micrometer fixed to a special device attached to a rigid carriage on the flume instrument rails, as shown in Figure 1.2 .

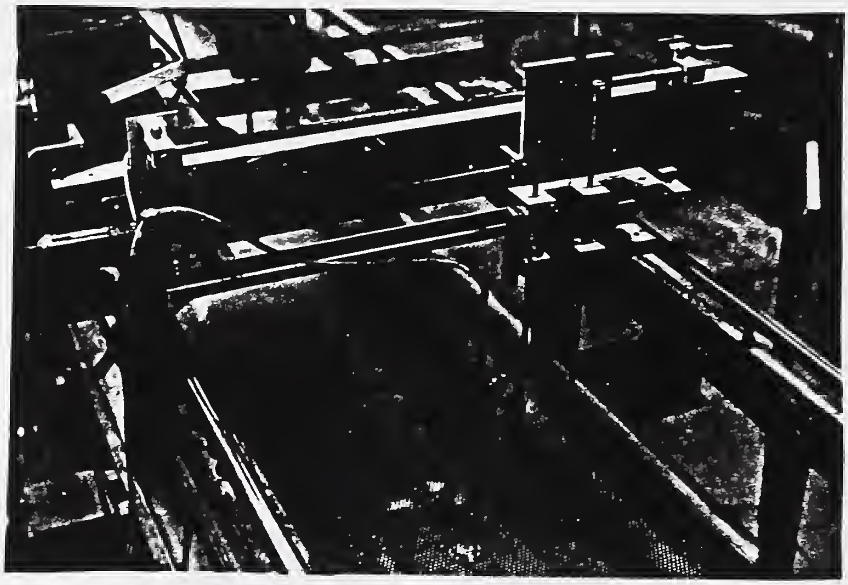


Figure 1.2 : The Positioning device

The velocity probe was a simple copper total-head tube with an external diameter of 3.10 mm. The tube wall at the tip was made as thin as possible by forming an internal wedge with an angle of 10 degrees. This minimized but did not entirely eliminate, wall proximity error. The difference between the hydrostatic pressure, obtained through a piezometric tap in the flume channel bottom in the same section as the velocity probe tip, and the higher pressure obtained through the total head tube, was measured by a pressure transducer. The transducer had a tolerance of 0.5% of pressure range and was attached to an electronic device that displayed the differential pressure in Volts and could be calibrated to indicate the measured differential head.

Using a point gauge with an accuracy of 0.3048 mm, the pressure transducer and attached electronics were found to follow a linear variation satisfying the constant equivalence 1 Volt X 0.03048 m in the measured range. The calibration formula for converting Volts to velocity values was (with $g = 9.816\ m/sec^2$ and $C_p = 0.98$, $C_p\ [(0.06096\ g) = 0.758$):

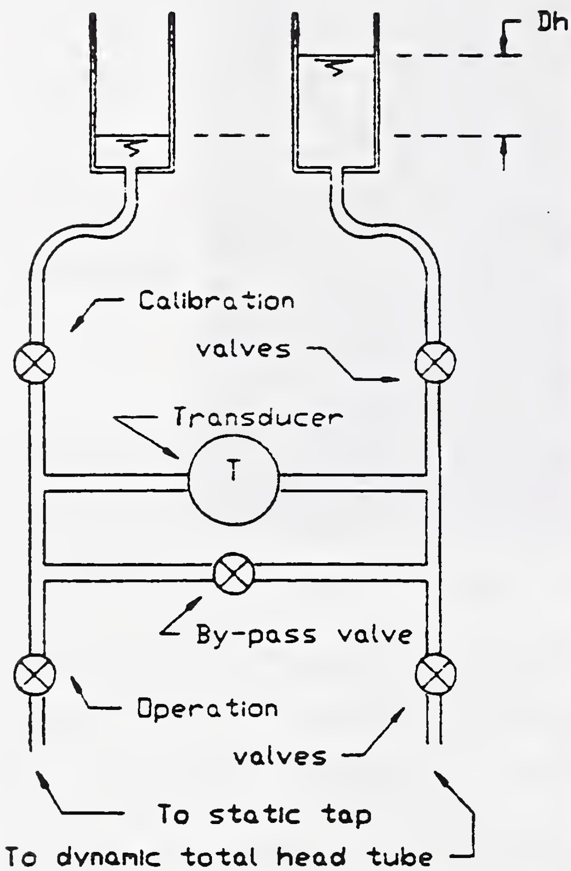
$$V[m./sec.] = 0.758\ [(Wh) \tag{1.1.1}$$

where V is the instantaneous velocity in m./sec. and Wh is the instantaneous sampled differential pressure in Volts.

The transducer hydraulic set-up used during data acquisition and calibration is shown in Figure 1.3. This combination of valves and tubes also serves to eliminate air bubbles from the transducer and the Pitot tube and allows backflushing to eliminate any trash collected by the tube orifice. The system zero and calibration could be checked at any time, and air bubbles could be purged without loss of calibration. During data acquisition, the system provided fast and relatively undamped response to velocity fluctuations.

A short, first battery of tests was conducted with flow over the original untreated steel flume bottom. Then the bed was painted with a commercially available plastic paint in an attempt to improve its smoothness. Two complete series of tests for the practicable range of discharges were conducted using the painted bed. Then a series of horizontal distributions of velocities at approximately 20 and 80 % of the depth was measured for two discharges to check the assumption of two-dimensional flow in the central part of the test section.

a) Sketch **b) Photography**



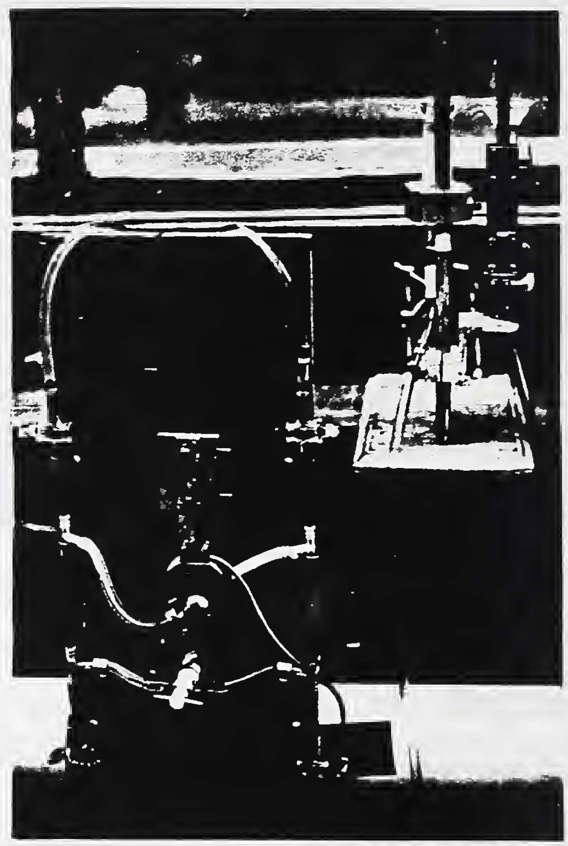


Figure 1.3 : The Transducer hookup device: a) Sketch, b) Photography

A representative rough bed was then formed by carefully laying a close packed bed of lead balls (Figure 1.4) with a diameter of 6.35 mm., over the whole length of the channel (Figure 1.5).

An extensive series of experiments was performed in flows over this rough bed, as described in Chapter 2.

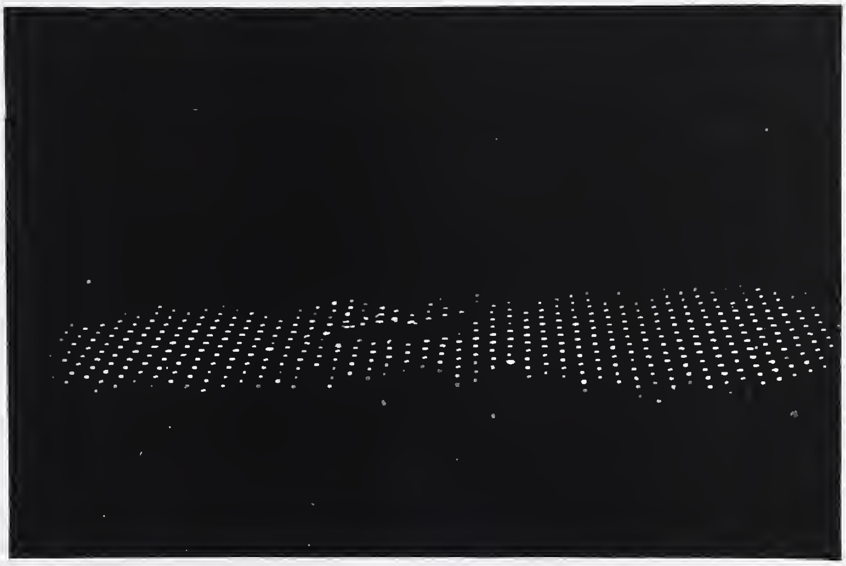


Figure 1.4 : The Packed bed of lead balls. Flow is parallel to the figure.

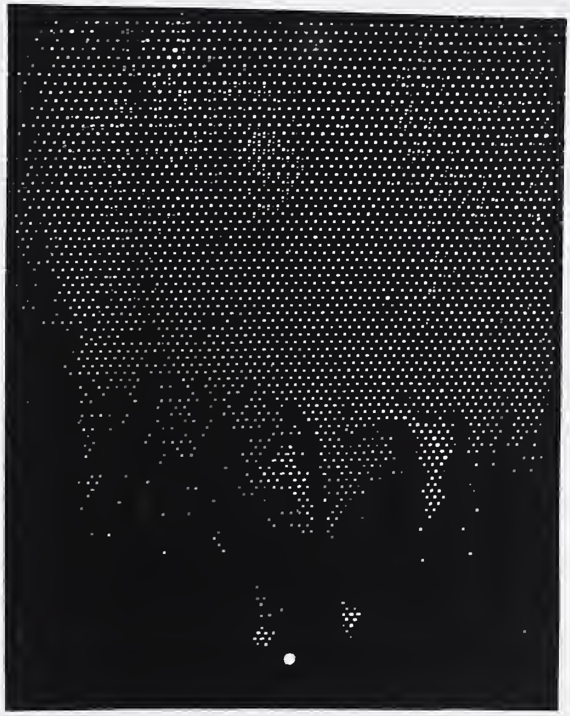


Figure 1.5 : A plan view of the channel bed furnished with lead balls.

1.3 The Program VELMEAS

The program VELMEAS Version 1 developed in the course of the present research acquires data in form of random signals and produces a statistical and deterministic analysis of the data collected.

The statistical analysis generates basic parameters for each probe position. The corresponding theory is summarized in section 2.2, and its computational implementation is described in section 4.5.

The deterministic analysis is essentially a consistent ensemble of existing theories concerning turbulent boundary layers, combined with some advances in previously developed techniques for treatment of these theories. An extensive use of polynomial correlation is also included. The theories used are summarized in sections 2.3 to 2.7, and their computational implementation in analysis is described in sections 4.6. to 4.8.

There is also a Regression facility in the program, useable for non-automatic analysis, which is an additional tool for the investigator (Section 4.6).

The program has been written in FORTRAN IV language to facilitate portability, which has been tested (See section 4.2). The data acquisition part however, is quite machine dependent (See section 4.4). A Main routine manages the whole analysis, facilitating future expansions (See section 4.3). Plotting is extensively used to ease the task of the investigator and to document the results in a comprehensive way (See section 4.8).

The source code is included in this report (Appendix A) as well as execution files used with two very different operating systems and machine environments (Appendix B). A detailed User Manual is also included as the Chapter 5.

The large number of different techniques and procedures that had to be merged to compose a comprehensive and consistent analysis was a cumbersome task. This may serve to partly justify the relative lack of "transparency" of the program.

1.4 Data acquisition and Statistical Analysis

When measuring instantaneous velocity values in a turbulent flow as a series of values sampled in rapid succession during a relatively large period of time, the resulting histogram is always in part characterized by the presence of intermitent episodes of sudden amplification of the background fluctu-tion, or bursts. The bursts are a typical result of turbulence and its associated eddy generation and destruction process. In addition to this, means obtained in different periods will change following a long-wave pattern, even after days of continuous operation, when mass oscillation in the flume due to the flow stablishing period has certainly been damped; this is due to the channel-pump-engine system for which an exact steady state can never be established, because of electrical fluctuations and mechanical oscillations.

When attempting to obtain mean-velocity distributions, the only remedy is to extend the data acquisition in each probe position and the subsequent statistical analysis over a sufficiently large period.

Every system will require a different period that should be determined by a series of tests that systematically increase the period of measurement in a well established flow. Tests conducted at the beginning of this research indicated a period of 5 minutes for a sample interval of 0.01 seconds is the shortest period for which stationary means could be obtained.

The statistical analysis generates basic parameters for measurements at each position, including the Mean, the Standard Deviation, the Probability Distribution of Frequencies (PDF) diagram and its Mode, Median, Skewness and Kurtosis, as well as the first to fourth Moments about the zero and about the Mean.

The PDF has been found to be a reliable auxiliary in determining when the system is steady enough for meaningful measurements. Mass oscillations appear as distinct peaks shown by the program on a conventional text-terminal screen. Theoretical considerations are presented in sections 2.2 and 2.3 and practical implementation in sections 4.5 and 4.6.

1.5. Boundary-Layer Analysis

The boundary-layer analysis of present measurements is in close agreement with the objectives stated in section 1.1. The Karman-Coles equation for distribution of velocities in boundary layers was selected as a basis of analysis, since it is a most general relationship including theoretical and factual considerations, and yet allows objective treatment when properly applied. It includes a logarithmic component, supported by a long record of observations and theoretical dimensional analysis, a functional decrement

depending upon channel roughness, and a "wake" function that allows a smooth transition between the logarithmic distribution and the outer flow. The wake function is nowadays a proven feature of turbulent boundary layers, confirmed by present experiments. The basic theory is presented in section 2.4, while non-dimensional equations are summarized in section 2.5. Secondary procedures that account for needed corrections of measurements due to the proximity of the probe to the bed and walls of the channel are outlined in section 2.7. Channel resistance to flow as expressed by the Darcy-Weisbach friction coefficient is estimated as described in section 2.8.

A large effort was directed toward computing the virtual origin distance from the reference origin used in making physical measurements and defining its influence in the mathematical expression of the velocity distributions. A computational procedure was developed that for the first time permits an automatic and precise determination of the virtual origin e for a given thickness of the inner sublayer.

The search for a virtual origin consists of an iterative procedure, in which a guess of its position is made and subsequently improved through a series of linear regression analyses that use the standard error of estimate s as selecting parameter; the correct virtual origin distance is the one that produces the least s. Section 2.6 details the analysis. If the thickness of the logarithmic region is precisely determined, the correct e value will be that determined by including in the analysis all and only those points included in this zone.

1.6. Conclusions and Recomendations

Present research proves that an objective definition of a virtual origin for measured velocity profiles in a bounded shear flow is attainable, provided adequate instrumentation is used, by means of a computational procedure. This procedure was developed and applied in the course of this investigation. The separation between the inner and outer flows is also recognized by the procedure, but its precise determination still requires further developments and more accurate measurements that the ones reported here. The best estimate of virtual origin ultimately depends upon the identification of the thickness of the inner region. However, the equipment used for data acquisition have not allowed that identification. More precise data would permit extensions of the analysis; although no precise computation of required accuracy has been executed, the authors believe that data acquired with hot-film or laser-Doppler anemometers (LDA) should suffice. Nevertheless, it is possible that carefully-obtained data using small-diameter Pitot tubes in very stable flows like those resulting from Nikuradse's experiments in pipes, may be successfully treated with this new procedure. It is possible to analyze long-ago obtained data in the light of new knowledge and extract new information. For example, Nikuradse's experiments are highly reliable; the apparent lack of wake effects in Nikuradse data may be disproved with the more accurate procedures for computing the virtual origin and its effects upon data alignment like the one here developed. Therefore, a new analysis of his comprehensive set of measurements is recommended. Also recent data obtained using LDA may yield new knowledge when treated with this new technique. Technical conclusions on data obtained in the course of this investigations are included in Chapter 3.

CHAPTER 2

THEORY AND METHODS USED IN THE ANALYSIS

2.1. Introduction

A number of procedures have been incorporated in the program VELMEAS to make possible an automated analysis of data collected in a laboratory flume (the analysis would in fact also be valid in part for any random signal collected through a sampling system). An extensive collection of rather simple techniques was merged in a single program providing an efficient and fast way of executing an otherwise cumbersome task.

Those parts of the present analysis that refer to velocity distributions are little more than a computational implementation of the theory recently outlined by Coleman (1985), and may be regarded as a consistent ensemble of well-known contributions of von Karman (1930), Schlichting (1937), Millikan (1938) and Coles (1956). Only techniques involving formulation or some mathematics are reported here. Chapter 4 (Program description) and in less measure Chapter 5 (User Manual) complement this account.

Each section in this chapter groups closely related techniques. A new procedure to find the actual origin of the velocity distribution (the point where the time-mean pointwise velocity is null) has been developed and is discussed in section 2.6.

2.2 Statistical Methods

In the flume experiments a total of 30,000 samples collected over a period of 5 minutes was taken at each probe position. A minimum of 20 and a maximim of 60 positions were measured for each velocity distribution investigated in the course of a single experiment. Since present research is concentrated on mean parameters of the distribution, such as the Karman coefficient, the intercept and the wake strength coefficients, the determination of a mean-temporal pointwise velocity for a single position is the most essential part of the analysis, as it is for any analysis involving turbulent flows. No measuring reliability can be assessed, however, without determining the standard deviation and investigating the characteristics of the frequency distributions. The latter is done by obtaining a Probability Distributions of Frequencies (PDF), and calculating its Skewness and Kurtosis.

One characteristic of PDF diagrams of velocities is that they are clearly positively skewed, particularly close to a wall, as evidenced by similar measurements made with hot films in a zero-pressure gradient flow by Wylie et al. (1977). Although the PDFs obtained by Wylie were well fitted by a theoretical two-parameter Gamma-density function at the corners of the cross section in the same laboratory flume used in the present study, the goodness of fit in the remaining (and more important) parts of the wetted perimeter was not satisfactory. The lognormal distribution as reported was even less satisfactory. The reason for these consistently found positive skewnesses is not known. It appears to be connected with the presence of large-scale eddies close to the wall. These eddies are more stable close to the corners, which may be the reason for more consistent results there.

To account for the aforementioned results, the use of a theoretical distribution was discarded, and the computation of actually measured PDF used instead.

The following classical formulation was used, as described by Yule and Kendall (1968), with N the number of samples, and V_i the measured-instantaneous velocity or sample.

Mean U:

$$U = \frac{1}{N} \sum_{i=1}^{N} V_i \tag{2.2.1}$$

Standard Deviation σ:

$$\sigma = \left\{ \frac{1}{N-1} \left[\sum_{i=1}^{N} (V_i^2) - \left(\sum_{i=1}^{N} V_i \right)^2 / N \right] \right\}^{1/2} \tag{2.2.2}$$

Equation (2.2.2) is the best suited form to compute σ for it does not require the previous computation of the Mean. In fact both summations of V_i and V_i^2 are done at the same time.

The analogic-digital converter has a certain resolution (in the present case 0.005 Volts) which is considered as a class interval. Hence values which are available in discretized fashion are counted. The number of times a certain class value V_j appears is divided by N to obtain the frequency f corresponding to that value. A PDF results, with M class values satisfying:

$$\sum_{j=1}^{M} f_j = 1 \tag{2.2.3}$$

$$U = \sum_{j=1}^{M} f_j V_j \tag{2.2.4}$$

$$\sigma = \left\{ \frac{1}{N-1} \left[\sum_{j=1}^{M} (f_j V_j^2) - \left(\sum_{j=1}^{M} f_j V_j \right)^2 / N \right] \right\}^{1/2} \tag{2.2.5}$$

The skewness S_k and kurtosis K_u can also be computed by using the PDF. If d is the distance between the mean and an arbitrary origin o:

$$d = U - o \tag{2.2.6}$$

the nth-Moment about the origin would be given by:

$$T'_n = \sum_{j=1}^{M} f_j (V_j - o)^n \tag{2.2.7}$$

Since the origin is arbitrary, we choose $o = 0$ (zero) and equation (2.2.7) becomes:

$$T'_n = \sum_{j=1}^{M} f_j V_j^n \tag{2.2.8}$$

while d = U. The nth-Moment about the mean however requires knowing the mean:

$$T_n = \sum_{j=1}^{M} f_j (V_j - U)^n \tag{2.2.9}$$

It is advantageous to compute first the moments about the origin, for this can be done simultaneously with the computation of U and σ in terms of the frequencies. Then the moments about the mean can be computed from those about the origin by means of equations (2.2.10) to (2.2.13) (See Yule and Kendall, 1968):

$$T_1 = 0 \tag{2.2.10}$$

$$T_2 = \sigma^2 \tag{2.2.11}$$

$$T_3 = T'_3 - 3dT'_2 + 2d^3 \tag{2.2.12}$$

$$T_4 = T'_4 - 4dT'_3 + 6d^2T'_2 - 3d^4 \tag{2.2.13}$$

It has been shown that if the distribution of frequencies tapers off to zero

in both directions, which is the case, the following Sheppard's corrections are to be introduced (The sub-index c indicates the corrected value and Δ is the class interval):

$$T_{2c} = T_2 - \Delta^2/12 \tag{2.2.14}$$

$$T_{4c} = T_4 - 0.5\Delta^2 T_2 + (7/240)\Delta^4 \tag{2.2.15}$$

The following parameters are next derived from these moments:

$$\beta_1 = \frac{T_3^2}{T_{2c}^3} \tag{2.2.16}$$

$$\beta_2 = \frac{T_{4c}}{T_{2c}^2} \tag{2.2.17}$$

from which the skewness S_k and kurtosis K_u are computed:

$$S_k = \left[\frac{(\beta_1)^{1/2}(\beta_2 + 3)}{2(5\beta_2 - 6\beta_1 - 9)}\right] \cdot \mathrm{Sgn}(U - U_a) \tag{2.2.18}$$

$$K_u = \beta_2 - 3 \tag{2.2.19}$$

Here U_a is the median, which is the V class value for which the cumulative continuous distribution of frequencies (CDF) is equal to one half, i.e., $\int f(V)dV = 0.50$. The original form of equation (2.2.18) does not allow the determination of the skewness sign, but gives the absolute value of the ratio. The function $\mathrm{Sgn}(U-U_a)$ used as a factor gives a consistent definition of the skewness sign. The theoretical reference for determining the sign of S_k should actually be the Mode M_o, which is the class value for which f is maximum, rather than the median. However, the PDF has in practice small local peaks that may alter the position of the mode. The median, obtained by accumulated integration starting from the minimum registered class value, is a much more reliable parameter than the mode.

2.3 Correlation Methods

Polynomial regressions are used to obtain faired curves through the pointwise time-means (which will be called "observations"). Polynomial regressions are a subset of the set of multiple regressions. A regression value U will be obtained from (Carnahan et al., 1969):

$$U = a + b_1x_1 + b_2x_2 + \ldots\ldots + b_nx_n \qquad (2.3.1)$$

where $x_1, x_2, \ldots., x_n$ are n different variables.

A polynomial or curvilinear regression of n-th order is that special case of multiple regression for which $x_1 = y$, $x_2 = y^2$, ..., $x_n = y^n$, or:

$$U = a + b_1y + b_2y^2 + \ldots\ldots + b_ny^n \qquad (2.3.2)$$

If there are m observations U_k corresponding to positions y_k, the following n x n coefficients C_{ij} and n coefficients C_{iU}:

$$c_{ij} = \sum_{k=1}^{m} y_k^{i+j} - \left[\frac{\sum_{k=1}^{m} y_k^i \cdot \sum_{k=1}^{m} y_k^j}{m}\right] \qquad (2.3.3)$$

$$c_{iU} = \sum_{k=1}^{m} y_k^i U_k - \left[\frac{\sum_{k=1}^{m} y_k^i \cdot \sum_{k=1}^{m} U_k}{m}\right] \qquad (2.3.4)$$

lead to the linear system of n equations with n unknowns b_j:

$$\sum_{j=1}^{n} c_{ij}b_j = c_{iU} \qquad (2.3.5)$$

which, when solved, yield the values of the regression coefficients b_j of equation (2.3.2). The intercept a in the same regression equation is obtained from:

$$a = \overline{U} - \sum_{i=1}^{n} b_i\overline{y}^i \qquad (2.3.6)$$

where $\bar{U}$ and $\bar{y}$ are means of the regression data.

The error of estimate σ is obtained by calculating yet another coefficient:

$$c_{UU} = \sum_{k=1}^{m} U_k^2 - \frac{[\sum_{k=1}^{m} U_k]^2}{m} \tag{2.3.7}$$

which is used into next equation:

$$\sigma = \left(\frac{1}{m-n-1} [c_{UU} - \sum_{i=1}^{n} b_i c_{iU})] \right)^{1/2} \tag{2.3.8}$$

It should be noticed that there are only m-n-1 degrees of freedom, because n+1 coefficients have been estimated from the data. Hence a larger polynomial order, while giving higher flexibility to the fitting, tends to degrade the quality of the approximation by increasing σ, unless m is much higher than n. The standard error of estimate σ is used to judge the relative fitting quality of different polynomial regressions.

In the present research the independent variable y is usually transformed by the natural logarithms. If the dependent variable is also converted, the goodness of fit should be done after applying the inverse of the transformation function to the resultant σ.

Sometimes the solution of the system of equations offers difficulties. The Gauss-Jordan reduction method with pivoting strategy (Carnahan et al., 1969) was found quite efficient in producing appropiate solutions.

2.4 The law of the wall and the law of the wake

Channel flows belong to the general class of inner bounded-shear flows, as do pipe flows, flows around airplane components or ship hulls, and even flows in rivers (despite their complicated countour and roughness variability). There often is a need for computing the distribution of velocities in the boundary layer that forms at least close to any boundary and that sometimes occupyies the whole extent of the flow. Figure 2.1 illustrates a typical velocity distribution, in this case one measured in a laboratory flume by the writers using a simple Pitot tube (The curve through the points is a polynomial obtained applying the procedure described in section 2.3; see section 2.5 for the definition of the graph coordinates).

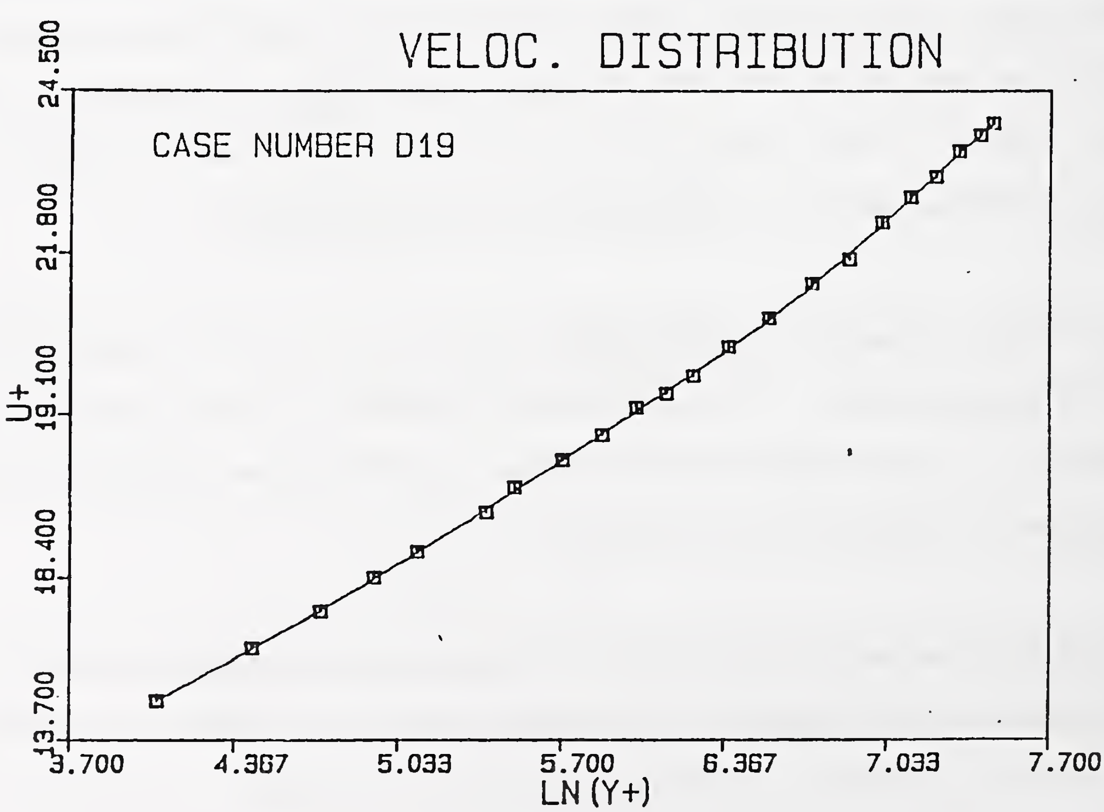


Figure 2.1 : A measured velocity distribution.

Figure 2.2 shows a more complete profile prepared by Cebeci and Smith (1974) from data obtained by Klebanoff in 1954, with a classical description of the boundary layer in terms of regions and sub-layers.

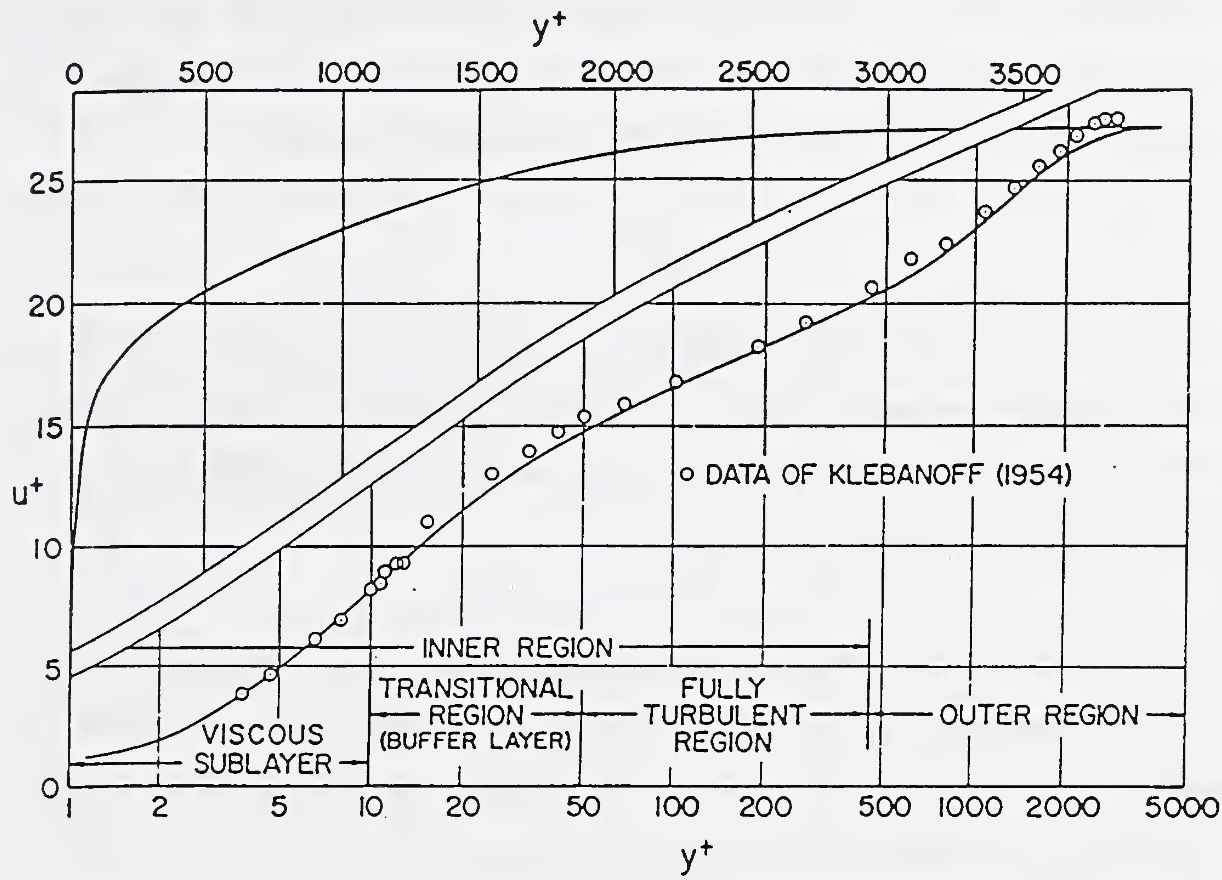


Figure 2.2 : The boundary-layer regions (After Cebeci and Smith, 1974).

Since a thin viscous sublayer and a buffer layer (altogether, approximately the lower 10 % of the inner region or the lower 1 % of the boundary layer) were out of reach of the probe in present study, the measured velocity distribution in Figure 2.1 may be represented by the Karman-Coles equation (Coles, 1956). It accounts for the fully-turbulent region (approximately the upper 90 % of the inner region) and the outer region (approximately the upper 90 % of the boundary layer).

The Karman-Coles equation is presently written

$$\frac{U}{U_*} = \frac{1}{\kappa}\,\ell n\left(\frac{U_* y}{\nu}\right) + A - \frac{\Delta U}{U_*} + \frac{\Pi}{\kappa}\,\omega\left(\frac{y}{\delta}\right) \tag{2.4.1}$$

In equation (2.4.1), κ is the von Karman parameter and ν is the kinematic viscosity, U is the pointwise time-mean velocity, y is the distance from origin (where U = 0), and U_* is the shear velocity, given by:

$$U_* = \left[\frac{\tau_o}{\rho}\right]^{1/2} \tag{2.4.2}$$

with τ_o the shear stress at the wall, and ρ the fluid density. Π is the "wake strength parameter" and ω is the "wake function" introduced by Coles (1956), discussed below. The term $\Delta U/U_*$ is the "velocity decrement" which depends upon the channel roughness.

Very close to U = 0 there is essentially no room for turbulence so that viscosity dominates and the original Boussineq's proportionality between the gradient of velocity and shear stress applies (with $\mu = \nu\rho$, "dynamic viscosity", the coefficient of proportionality):

$$U_*^2 = \frac{\tau_o}{\rho} = \nu\,\frac{\partial U}{\partial y} \tag{2.4.3}$$

from which, integrating,

$$\frac{U}{U_*} = \frac{U_* y}{\nu} \tag{2.4.4}$$

This equation (2.4.4) is the "viscous law of the wall", valid in the viscous sublayer, proximate to the origin of the velocity distribution. This region is not represented in Fig.2.1 because it could not be resolved by the velocity probe used. If the outer region is also excluded from the data in

Figure 2.1, the remaining points closely align themselves on a linear pattern (when plotted in U^+, $\ell n(y^+)$ coordinates), as in Figure 2.3. This is the "fully-turbulent law of the wall". It is also known as the "logarithmic part" of the velocity distribution because its mentioned graph properties. It is represented by the first two terms on the right-hand side of eq. (2.4.1). It has been found for many researchers not to exceed (unless the Reynolds number is very small) about 10 to 20 % of the total boundary layer.

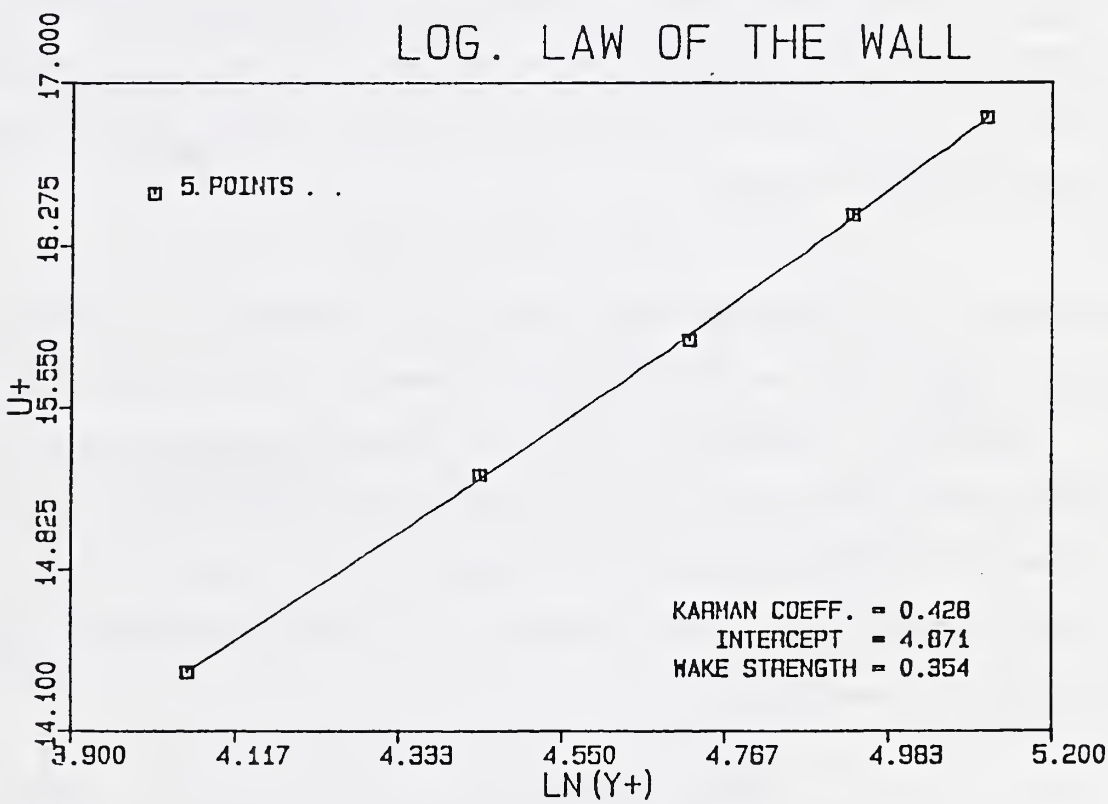


Figure 2.3 : A measured fully-turbulent law of the wall.

The over-stating term "law" somewhat obscures the fact that eq.(2.4.1) and (2.4.4) are mere phenomenologic relationships. However its use is customary. The buffer region is a transitional zone between the viscous and fully-

turbulent laws. According to assumptions needed to derive equation (2.4.4) from eq.(2.4.3) the shear-stress is constant in the viscous sub-layer. In the buffer zone, turbulence grows rapidly and the gradient of shear-stress should be expected to reach a maximum. Outside the viscous sub-layer, the Boussinesq relationship includes the correlation uv (u and v are the fluctuating components of time-mean pointwise velocity components U and V):

$$\frac{\tau}{\rho} = \nu \frac{\partial U}{\partial y} - \overline{uv} \qquad (2.4.5)$$

The first two terms to the right of equal sign in equation (2.4.1) are the log-linear part of the distribution of velocities, i.e. the fully-turbulent law of the wall. The last term is the non-linear part, and it has been named the "law of the wake" by Coles.

The existence of the wake has been consistently confirmed by a number of researchers (See Cebeci and Smith, 1974 ; Coleman, 1981 ; Nezu and Rodi, 1986). Again its mathematical form is unknown and phenomenological relationships have been built by using measured data. The first and most used is that of Coles, written here as equation (2.4.6). Other fittings have been made by other authors such as Finley et al. (1966) who expressed it as the polynomial in equation (2.4.7).

$$\omega(\frac{y}{\delta}) = 2 \sin2(\frac{\pi}{2} \frac{y}{\delta}) \qquad (2.4.6)$$

$$\omega(\frac{y}{\delta}) = \frac{\kappa}{\Pi}(\frac{y}{\delta})(1 - \frac{y}{\delta}) + 2(\frac{y}{\delta})^2[3 - 2(\frac{y}{\delta})] \qquad (2.4.7)$$

Figure 2.4 serves to compare Coles' and Finley's "laws" with a measured wake obtained in the course of this research. As expected, it confirms the existence of the wake.

The case shown was fitted with κ = 0.428, A-$\Delta U/U_*$ = 4.871 and Π = 0.370; the standard error of estimate for the law of the wall was σ = 0.0324, while U_m/U_* = 24.038 , $U_*\delta/\nu$ = 1743, U_* = 25.26 mm, and ν = 0.924 mm2/sec.

A consistent definition for the velocity decrement in eq.(2.4.1) was given by Schlichting (1937) who first introduced the "equivalent roughness" concept and the use of the "equivalent roughness" k leading to equation (2.4.8) and, by replacement of this into eq.(2.4.1), to equation (2.4.9). Nikuradse's (1950) "equivalent-sand roughness" k_s obtained through his famous pipe experiments is a direct derivation of this concept. The velocity decrement is

$$\frac{\Delta U}{U_*} = \frac{1}{\kappa} \ell n(\frac{U_* k}{\nu}) + B \qquad (2.4.8)$$

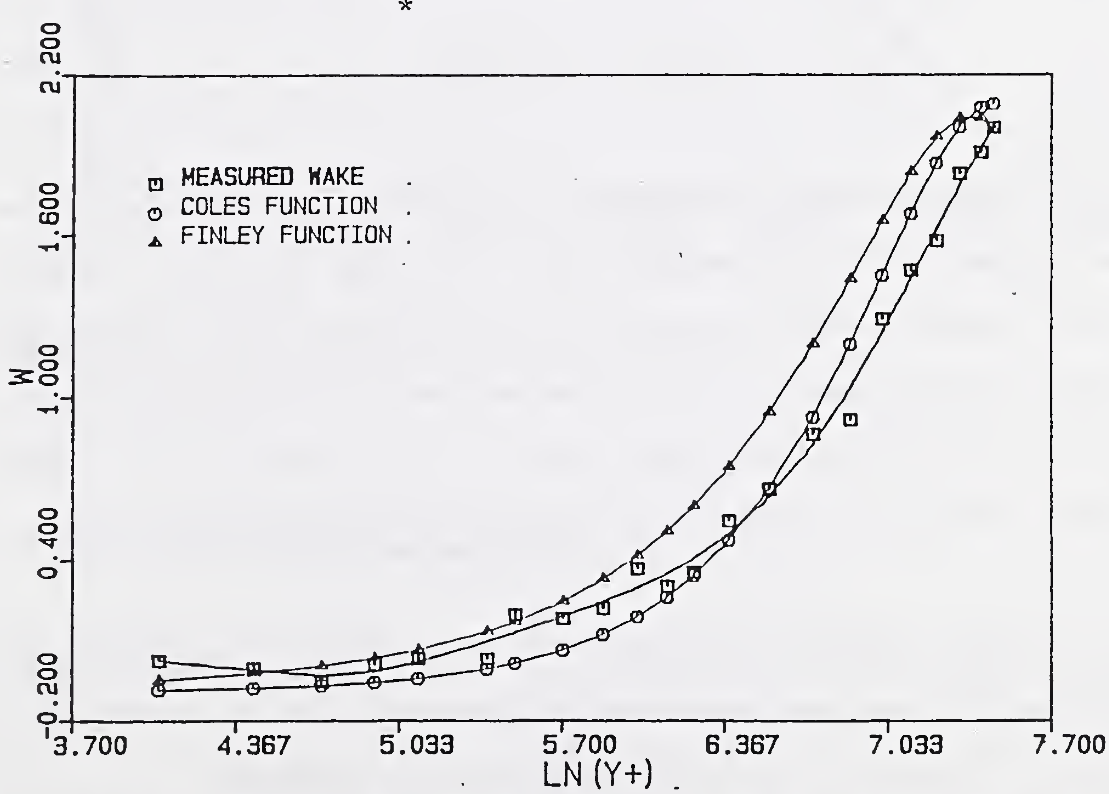


Figure 2.4 : Comparison between a measured law of the wake and the predicted by Coles' and Finley's laws (Π = 0.370).

In Schlichting-Nikuradse rough-wall terms,

$$\frac{U}{U_*} = \frac{1}{\kappa} \ell n(\frac{y}{k}) + C + \frac{\Pi}{\kappa} \omega(\frac{y}{\delta}) \tag{2.4.9}$$

Clearly, the coefficient C in equation (2.4.9) is given by:

$$C = A - B \tag{2.4.10}$$

Coles's function ω has the limits 0 for $y = 0$ and 2 for $y = \delta$. U would be maximum for the superior limit, i.e., $U = U_m$. In this case, equation (2.4.1) yields:

$$\frac{U_m}{U_*} = \frac{1}{\kappa} \ell n(\frac{U_* \delta}{\nu}) + A - \frac{\Delta U}{U_*} + 2\frac{\Pi}{\kappa} \tag{2.4.11}$$

Substracting equation (2.4.1) from equation (2.4.11), the Prandtl-Karman-Coles "velocity-defect law" results:

$$\frac{U_m - U}{U_*} = - \frac{1}{\kappa} \ell n(\frac{y}{\delta}) + \frac{2\Pi}{\kappa} - \frac{\Pi}{\kappa} \omega(\frac{y}{\delta}) \tag{2.4.12}$$

The velocity-defect law has the advantage in both forms of the velocity law that the argument in the two variable terms is the same ratio y/δ. The non-linear part clearly becomes asymptotic to the log-linear part, allowing the definition, to some degree, of a limit between the inner and outer regions; hence the slope of the linear part, which is the inverse of the Karman coefficient. Figure 2.5 displays one measured velocity-defect law.

Finally, the wake strength parameter Π can be computed by projecting the straigth line fit from the asymptotically logarithmic part of the data plot up to $y = \delta$. From eq.(2.4.11) this is equivalent to computing

$$\Pi = 0.5 \left[\kappa(\frac{U_m}{U_*} - A') - \ell n(\frac{U_* \delta}{\nu}) \right] \tag{2.4.13}$$

where A' is the intercept from the U^+, y^+ graph, for which:

$$A' = A - \frac{\Delta U}{U_*} \tag{2.4.14}$$

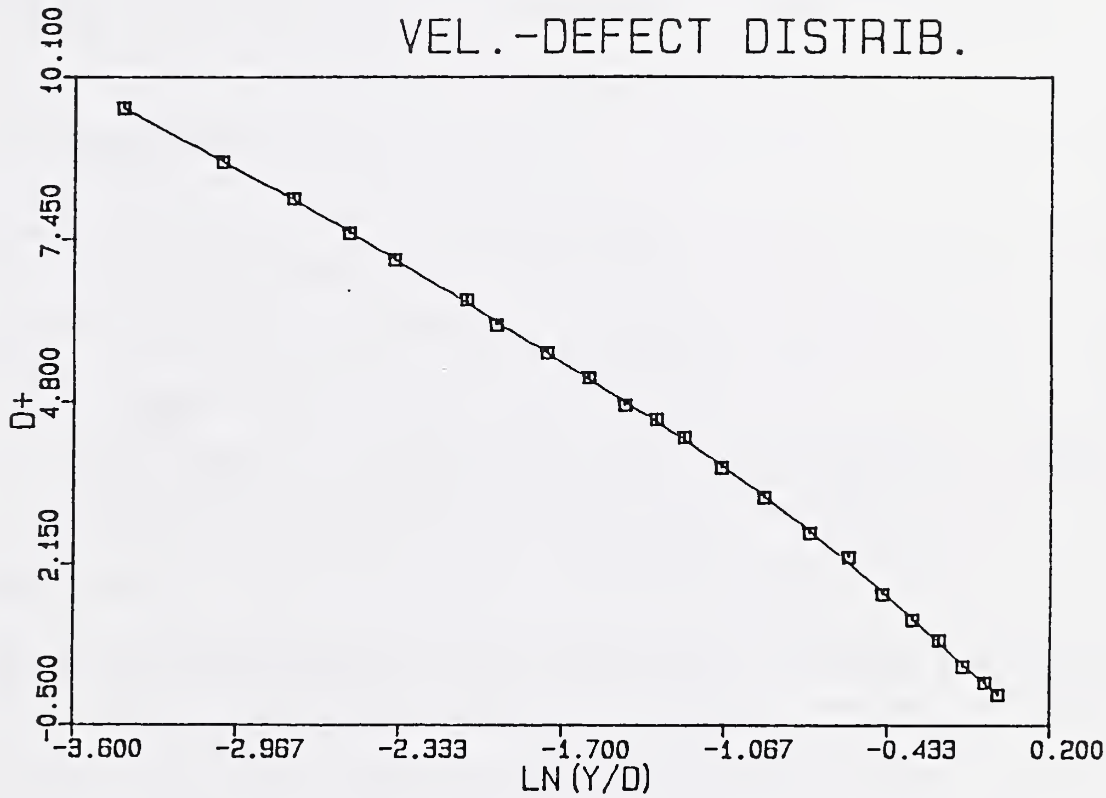


Figure 2.5 : A measured velocity defect law.

2.5 Dimensionless-variables equations

Dimensionless coordinates y^+, U^+ are defined by the following two equations:

$$y^+ = \frac{U_* y}{\nu} \tag{2.5.1}$$

$$U^+ = \frac{U}{U_*} \tag{2.5.2}$$

Similarly other dimensionless variables are defined in following equations:

$$\Delta U^{+} = \frac{\Delta U}{U_{*}} \tag{2.5.3}$$

$$k^{+} = \frac{U_{*}k}{\nu} \tag{2.5.4}$$

$$\delta^{+} = \frac{U_{*}\delta}{\nu} \tag{2.5.7}$$

$$\xi = \frac{y}{\delta} = \frac{y^{+}}{\delta^{+}} = \xi^{+} \tag{2.5.8}$$

$$\zeta = \frac{y}{k} = \frac{y^{+}}{k^{+}} = \zeta^{+} \tag{2.5.9}$$

By additionally defining an inverse s of von Karman's κ coefficient,

$$s = \frac{1}{\kappa} \tag{2.5.10}$$

the set of laws become (s is the slope of the log-linear part of the graph):

$$U^{+} = s\ \ell n(y^{+}) + A - \Delta U^{+} + s\Pi\ \omega(\xi^{+}) \tag{2.5.11}$$

$$\Delta U^{+} = s\ \ell n(k^{+}) + B \tag{2.5.12}$$

$$U^{+} = s\ \ell n(\zeta^{+}) + C - + s\Pi\ \omega(\xi^{+}) \tag{2.5.13}$$

$$U_{m}^{+} = -s\ \ell n(\delta^{+}) + A - \Delta U^{+} + 2s\Pi \tag{2.5.14}$$

$$D^{+} = U_{m}^{+} - U^{+} = -s\ \ell n(\xi^{+}) + s\Pi[2 - \omega(\xi^{+})] \tag{2.5.15}$$

$$\Pi = 0.5\ [\ \kappa(U_{m}^{+} - A') - \ell n(\delta^{+})\ ] \tag{2.5.16}$$

$$A' = A - \Delta U^{+} \tag{2.5.17}$$

Although the physical properties become a little obscured, this dimensionless form of the equations displays their graph properties. For instance, equation (2.5.5) for the velocity defect D^+ has a non-linear component $s\Pi\omega(\xi)$ (which is the wake) and a log-linear one. The log-linear part has an intercept equal to $2s\Pi$, which is the value of the wake at its maximum.

2.6 Virtual Origin

The problem of determining the origin of the y axis for a velocity profile is not only a theoretical problem but a first-order practical one, for an error in its determination may affect the fitting of the velocity-distribution laws. Theoretically, the exact origin should be the elevation at which $U = 0$ (see Figure 2.6). If the solid boundary of the flow being examined were in fact absolutely smooth and truly planar, the problem would not arise, as $(y=0, U=0)$ would exactly coincide with the solid surface. In practice, this point is hardly ever known a priori. For example, experimental data may be taken in a flume channel with a bottom composed of metal sheet, which to the eye may appear to be perfectly smooth and planar. Yet small surface undulations and a very small roughness texture may still cause significant uncertainties in the origin of y. The problem is aggravated when boundaries of larger roughness elements are considered. The resolution of the origin uncertainty becomes of first importance.

The effect of virtual origin uncertainty can be demostrated by an exercise involving Figure 2.1. If the origin of y^+ is changed by adding an arbitrary constant ϵ^+, say with a value of 60, and the data points are replotted on the original graph as $(U^+, \ell n(y^+ + \epsilon^+))$, the data points will rearrange themselves

closely along a log-linear function that can be drawn in by hand. If the process is repeated using $\epsilon^+ = 30$, another log-linear function will result, and the reader will not be able to discern, by the eye, which is better; that is which is the "right" function, for the data points will appear to fit either function equally well. The reader is then presented with a dilemma, since the inverse slopes of the respective functions will give different values of the Karman coefficient κ. The reader may refine the procedure to account for the wake effect by selecting only those points in the lower 10 to 20 percent of the boundary layer for finding κ from inverse slopes. The results will then be even more dismaying, for many of the possible tentative ϵ^+ values will lead to seemingly good fits, and diverse κ values.

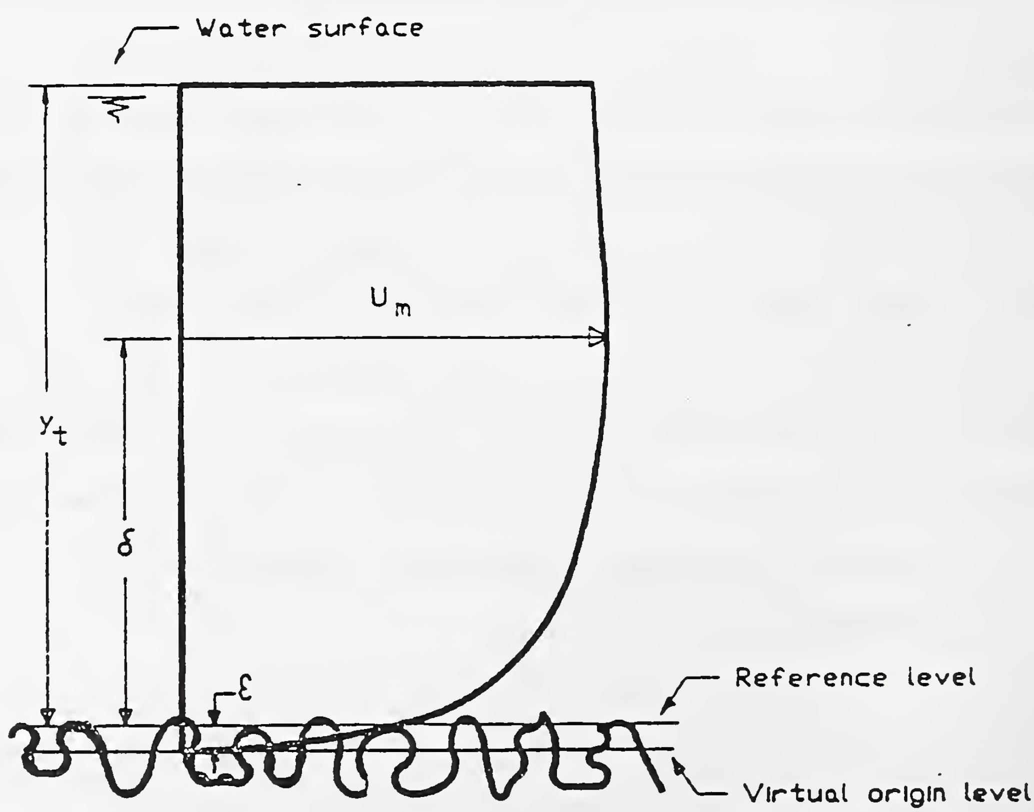


Figure 2.6 : Virtual origin definition sketch.

In velocity profile measuring techniques, the problem may be attacked by defining the elevation of each measuring point relative to an arbitrary elevation presumed to be near the virtual origin; the plane of the tops of uniform roughness elements is an example of a convenient reference elevation. The elevation y will be called the "position" of a measuring point, to be registered during data acquisition, and the real distance from the measuring point to the virtual origin will be $y + \epsilon$, where ϵ is a virtual origin correction.

The correctionn ϵ also has a dimensionless form ϵ^+ defined by

$$\epsilon^+ = \frac{U_* \epsilon}{\nu} \tag{2.6.1}$$

so that a "virtual distance" $\eta = y + \epsilon$, and its correspondent nondimensional form

$$\eta^+ = y^+ + \epsilon^+ \tag{2.6.2}$$

can be defined, as well as a new ratios λ and β given in equations (2.6.3) and (2.6.4) to replace eqs.(2.5.8) and (2.5.9) (Notice that $\lambda = \lambda^+ \neq \xi = \xi^+$ and similarly for β.):

$$\lambda = \frac{y + \epsilon}{\delta + \epsilon} = \lambda^+ \tag{2.6.3}$$

$$\beta = \frac{y + \epsilon}{k + \epsilon} = \beta^+ \tag{2.6.4}$$

The nondimensional equations of section 2.5 are hence rewritten in terms of virtual distance as:

$$U^+ = s\ \ell n(\eta^+) + A - \Delta U^+ + s\Pi\ \omega(\lambda^+) \tag{2.6.5}$$

$$\Delta U^+ = s\ \ell n(k^+ + \epsilon^+) + B \tag{2.6.6}$$

$$U^{+} = s\ \ell n(\beta^{+}) + C - + s\Pi\ \omega(\lambda^{+}) \qquad (2.6.7)$$

$$U_m^{+} = s\ \ell n(\delta^{+} + \epsilon^{+}) + A - \Delta U^{+} + 2s\Pi \qquad (2.6.8)$$

$$D^{+} = U_m^{+} - U^{+} = -s\ \ell n(\lambda^{+}) + s\Pi[2 - \omega(\lambda^{+})] \qquad (2.6.9)$$

$$\Pi = 0.5\ [\ \kappa(U_m^{+} - A') - \ell n(\delta^{+} + \epsilon^{+})\ ] \qquad (2.6.10)$$

The problem of determining an accurate estimate of ϵ (or ϵ^{+}) has proven to be, as remarked by Perry and Joubert (1963), "one of the most difficult tasks". They developed a graphic procedure that uses a monotonic curve of best fit faired by eye through the initial U(y) data points after introducing a tentative value of ϵ. The faired curve is then iteratively corrected by introducing new estimates of ϵ to produce a family of nearly straigth lines (at least in the lower portion of the boundary layer). The idea is that the line associated with the correct ϵ-value will lie in the range of ϵ-values where the inflection direction of the plotted curves is seen to change. They report that They "after much experimenting... found that the... method, although not giving the precise value of ϵ, locates the narrowest range within it occurs".

The method used in the course of the present research improves that of Perry and Joubert (1963) by allowing a determination of ϵ with precision dependent only upon initial data accuracy, by using regression analysis and an iterative method. The procedure also defines a distinction between the inner logarithmic and outer wake regions. It is fully computational and does not require graphics, although graphics has been included in the implementation anyway for illustration and further analytic purposes.

The procedure defines an initial arbitrary $\Delta\epsilon = 1$ mm. increment, as well as an initial value $\epsilon = \Delta\epsilon$ (Actually equivalent dimensionless variables are used instead). Then those near-boundary points that are most probably in the logarithmic region are fitted with a quadratic polynomial regression of U^+ against $\ell n(y^+ + \epsilon^+)$. Next ϵ is incremented in $\Delta\epsilon$ and a new quadratic regression is obtained. The procedure is repeated until the regression coefficient b_2 corresponding to the quadratic term, changes in sign. The exact value of ϵ, for which $b_2 = 0$, would lie between its previous and last value; in that case the quadratic regression degenerates to a linear regression. To actually find it, the change of sign of b_2 is used as an indication to reverse and refine the search with the new increment being $\Delta\epsilon' = -0.4\ \Delta\epsilon$. The search continues tuning up the value of ϵ until $\Delta\epsilon$ falls below a selected tolerance. A standard error of estimate σ is also found for the resulting linear regression, upon completion of the iterative procedure.

Next, another point of higher y position is included in the search along with the preceding points, and the whole procedure is repeated. This is continued until a marked increment of the standard error of estimate σ indicates the beginning of the outer region (or wake). The set of points that yield the least value of σ is considered to pertain to the inner region. For this set, the Karman coefficient, the intercept, and the wake-strength coefficients are computed. Hence the law of the wall is determined, and by substraction, the law of the wake is computed.

Figure 2.7 displays seven final optimal linear regressions obtained by using this new procedure with different numbers of points (from 4 to 11 points). Intermediate quadratic regressions are not shown. The set of points and

polynomial regression to the left is the original law with $\epsilon = 0$. For each linear regression, the graph also indicates the number of points used, and three parameters: VK = κ, A, and E = ϵ^+. Whenever the outer region is reached, the inclusion of wake points produces an increase of the slope s hence a decrease of κ, and a decrease of A (which could eventually become negative). If all the wake is included, the wake strength becomes null. These are misleading results produced by the inclusion of the wake. That inclusion and thus the transition from logarithmic to wake region, is located in the variation of κ, A and Π as functions of h/δ, where h is the thickness of the region included in the computations (Figures 2.8 to 2.11), mainly in the form of a sharp increment of ϵ (Figure 2.10).

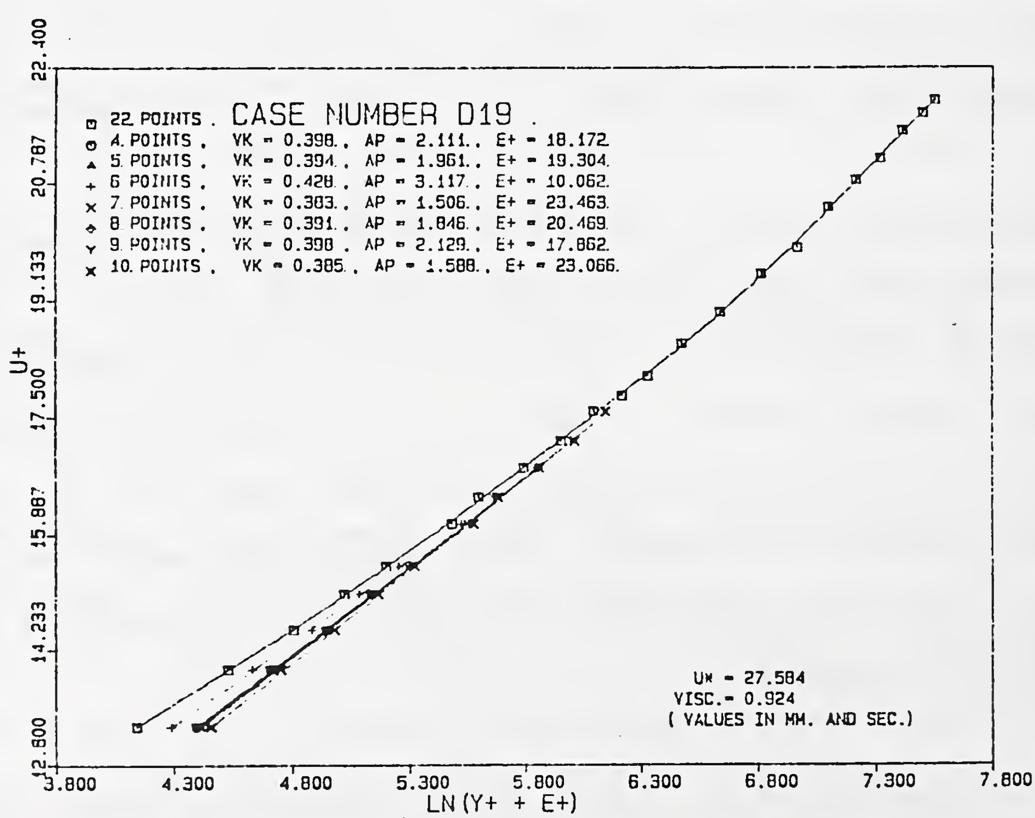


Figure 2.7 : Virtual origin search.

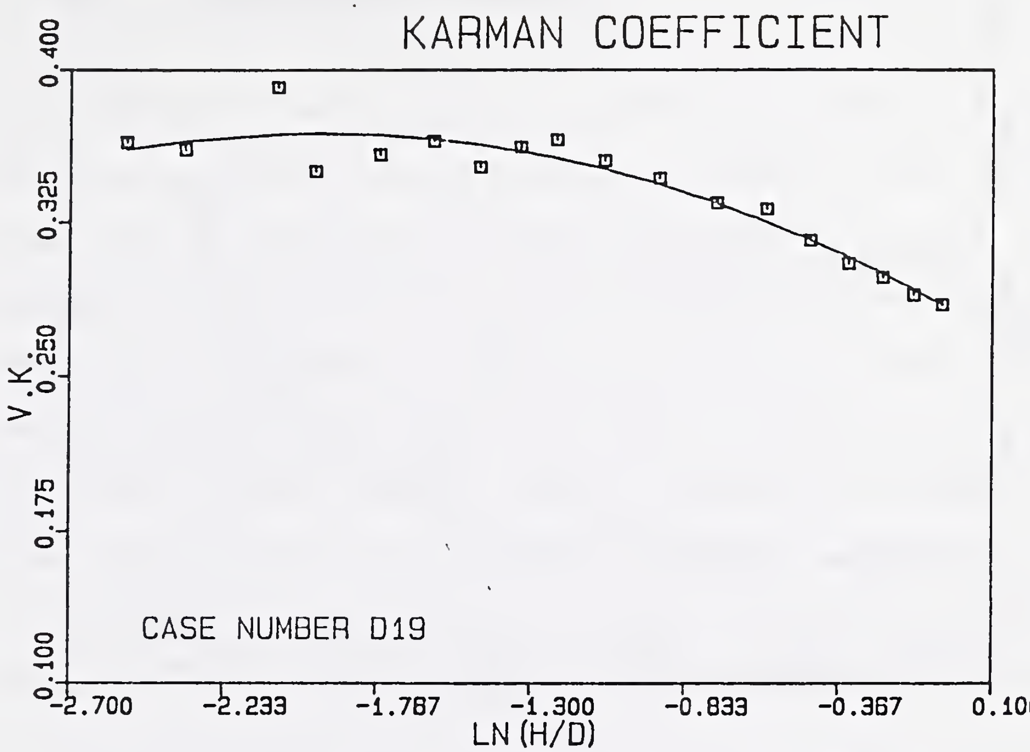


Figure 2.8 : Computed Karman coefficient during virtual origin search.

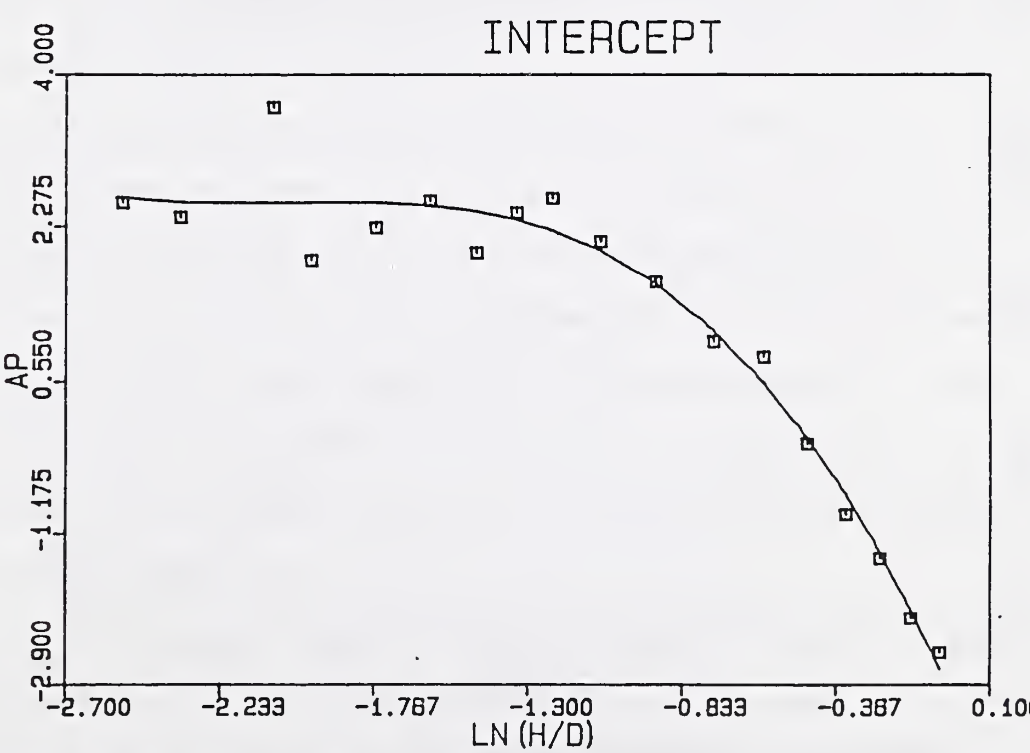


Figure 2.9 : Computed Intercept during virtual origin search.

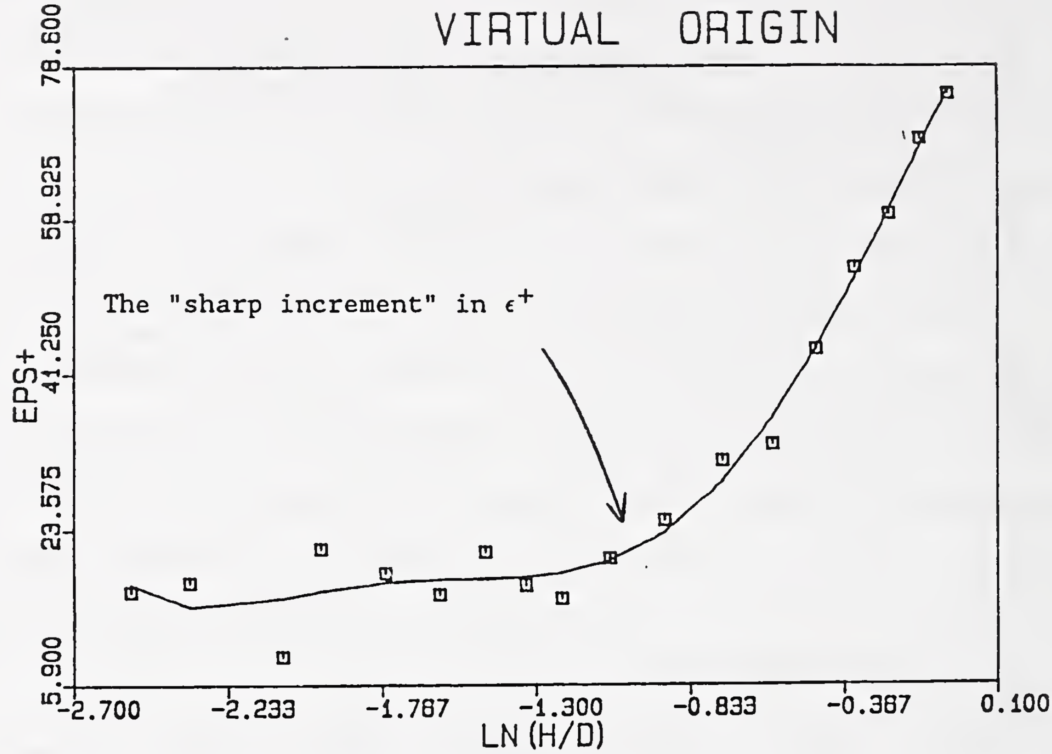


Figure 2.10 : The virtual origin as a function of search-region thickness.

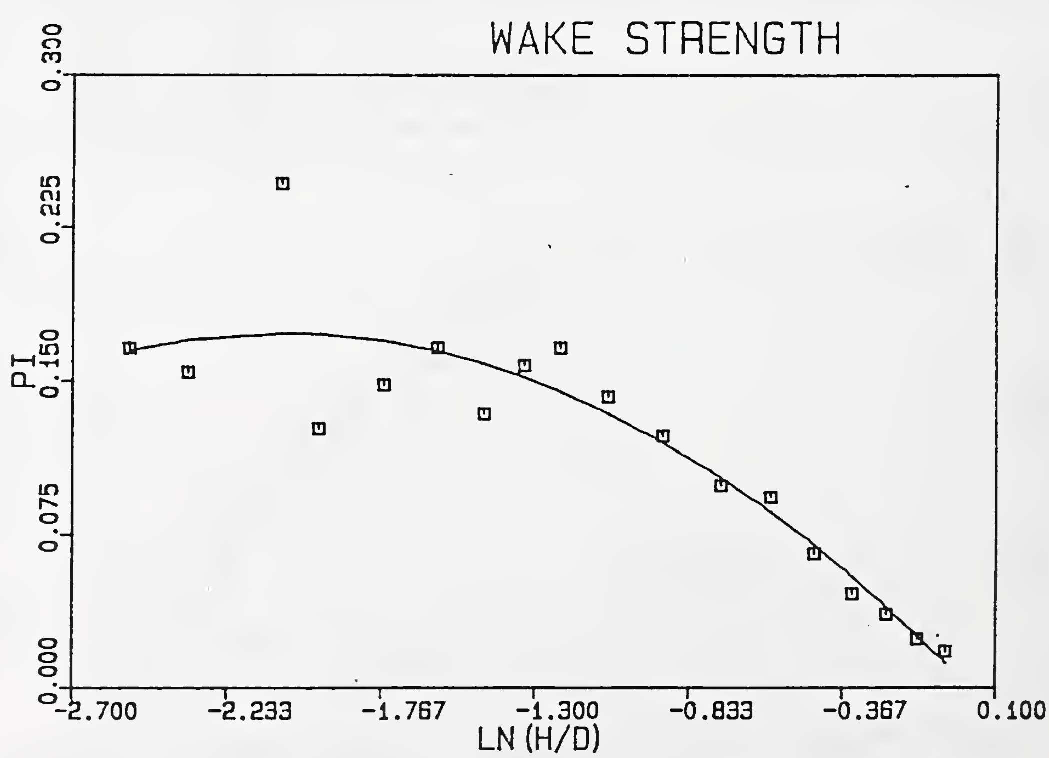


Figure 2.11 : Computed wake strength coefficient during virtual origin search

2.7 Bottom- and Wall-correction Methods

When the probe is inserted into a shear flow, the effective center of the Pitot tube is displaced from its geometrical center towards the region of higher velocity. Close to the bottom of the flume this effect is maximum, producing a rise in the effective probe position y. Since, as discussed in section 2.6, small errors in the estimation of y or ϵ distort the results sensibly, particularly for impact Pitot tubes of relatively large diameter, this "bottom proximity error" should be corrected. An ample review of investigations conducted to estimate the necessary correction was done by Daily and Hardison (1964). Several of those investigations give an upwards displacement of 0.18d or similar, where d is the tube-orifice diameter, when the tube is directly on the bed.

There is no information for cases in which the tube is near but not touching the bed. However, the effect should diminish and ultimately dissapear at some distance from the bottom that probably depends upon the diameter of the tube and the boundary layer thickness. A bottom correction function $y_c(y)$ should be asymptotic to the maximum correction (0.18d) at 0.5 d from the bottom (tube in total contact with the bed) and to zero at some distance y_m from the bottom. Such a function will be approximated by a cubic polynomial. Lacking more information, it was decided to define y_m of 10.5 d, i.e. to assume that the error vanishes at a distance of 10 tube diameters above the bed (See Figure 2.12).

The resulting correction function that should be added to the measured value y is:

$$y_c(y) = \sum_{i=1}^{4} c_i y^{i-1} \tag{2.7.1}$$

where $c_1 = 0.00036/d^2$, $c_2 = -0.00594/d$, $c_3 = 0.00567$, and $c_4 = 0.1786\ d$.

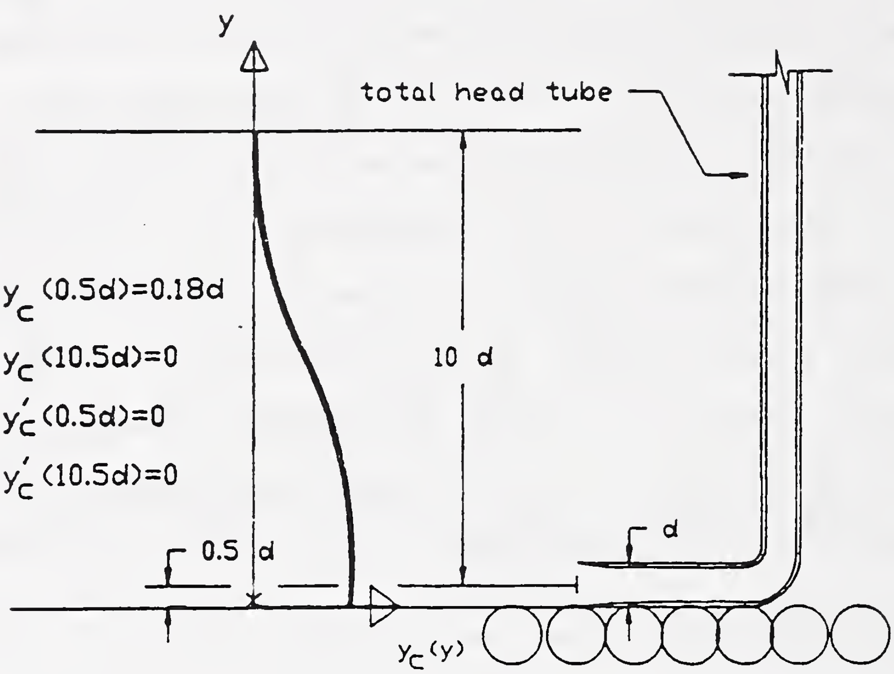


Figure 2.12 : Sketch of definition of bottom-proximity function.

The presence of the flume walls also has to be accounted because that alter the shear distribution across most of the flow from the wall towards the center of channel. Only for very wide channels may the central region be considered two dimensional. The problem is aggravated whenever different roughness is used on the bottom while maintaining a constant wall roughness as is common in flume experiments.

A method to produce a side-wall correction was originally developed by Johnson (1942) and later improved by Vanoni and Brooks (1957). The program developed in the course of this research incorporates this method in

automatic fashion. The independent variables in the present computational implementation are the slope of the energy line S, the temperature T, the acceleration of gravity g, the discharge Q, the cross-section width B and depth D.

A regression polynomial of order four (obtained with the program) permits calculating the kinematic viscosity as a function of temperature $\ell n(\nu) = P_{\nu}(T)$ (The standard deviation for ν is $e^{0.0026}$). Global parameters for the cross section including area Ω, wetted perimeter χ, mean velocity V, hydraulic radius r, shear velocity $U_{\star}$, Darcy-Weisbach friction factor f and Reynolds number $\mathbf{R}$, are obtained as usual from:

$$\Omega = Bh \tag{2.7.2}$$

$$\chi = B + 2D \tag{2.7.3}$$

$$V = Q/\Omega \tag{2.7.4}$$

$$r = \Omega/\chi \tag{2.7.5}$$

$$U_{\star} = \sqrt{(grS)} \tag{2.7.6}$$

$$f = 8(U_{\star}/V)^2 \tag{2.7.7}$$

$$\mathbf{R} = 4Vr/\nu \tag{2.7.8}$$

These global parameters are directly computed from the data.

The global cross section is considered to be divided into two sub-sections, namely a bed sub-section and a wall sub-section (the latter actually formed by two parts, one next to each wall). The bed sub-section produces shear on the bed, and the wall sub-section shear on the walls. The internal boundaries of the sub-sections are considered surfaces of zero shear. Equations 2.7.2 to 2.7.8 are applied to each sub-section as if each were an independent channel, by using a sub-index b (for bed) or w (for wall) in each case, and

$\Omega_b + \Omega_w = \Omega$. Roughness is homogeneous in each section although different between sections. However, velocity is assumed to be the same $V = V_b = V_w$. Furthermore, $\chi_b = B$ and $\chi_w = 2D$. With said assumptions it is easy to show that:

$$\frac{\mathbf{R}_w}{f_w} = \frac{\mathbf{R}}{f} \tag{2.7.9}$$

Since the ratio $\mathbf{R}/f$ can be computed directly, a function $f = \mathrm{func}(\mathbf{R}/f)$ will allow, through equation (2.7.9), obtaining an estimation of f_w, hence of $\mathbf{R}_w$. The procedure is a little tricky here, since in general the global f and $\mathbf{R}$ itself will not satisfy this relationship. Such a function is available in graph form in Vanoni and Brooks (1957) as obtained from a similar graph of f versus $\mathbf{R}$ for the Karman-Prandtl resistance equation for turbulent flow in smooth pipes. This function has been implemented in the program VELMEAS as a polynomial regression of order six (with a standard deviation $\sigma = 0.00030$ on f). Hence the wall parameters are succesively computed:

$$f_w = \mathrm{func}\left(\frac{\mathbf{R}_w}{f_w} \right) \tag{2.7.10}$$

$$\mathbf{R}_w = f_w \frac{\mathbf{R}}{f} \tag{2.7.11}$$

$$r_w = \frac{\mathbf{R}_w \nu}{4V} \tag{2.7.12}$$

$$U_{*w} = \surd(g r_w S) \tag{2.7.13}$$

A simple additional analysis yield the equations needed to compute similar bed parameters:

$$f_b = f + 2\frac{D}{B}(f - f_w) \qquad (2.7.14)$$

$$r_b = \frac{f_b}{f} \qquad (2.7.15)$$

$$U_{*b} = \sqrt{(g r_b S)} \qquad (2.7.16)$$

Finally estimates of the wall- and bed-shear stress ratios to the over-all average are obtained from:

$$\frac{\tau_b}{\tau_o} = \frac{r_b}{r} = \frac{f_b}{f} \qquad (2.7.17)$$

$$\frac{\tau_w}{\tau_o} = \frac{r_w}{r} = \frac{f_w}{f} \qquad (2.7.17)$$

Whenever the measurements are conducted close to the axis of the channel, the bed shear velocity U_{*b} is the best estimate for use in the equations discussed in section 2.7 .

2.8 Channel Resistance

An estimate of the Darcy-Weisbach coefficient f, for the purpose of obtaining a reasonable estimate of the shear velocity u_* was obtained in the previous section. However, once the equations for the distribution of velocity and their parameters are known, a more consistent value of f for the measured profile may be obtained.

By using the mean velocity in the measured vertical, U_a instead of the cross-section mean V, equation (2.7.7) is here rewritten:

$$\frac{1}{\sqrt{f}} = \frac{1}{\sqrt{8}} \frac{U_a}{U_*} \tag{2.8.1}$$

The profile mean velocity U_a is obtained by integrating through the depth

$$U_a = \frac{1}{y_t} \int_0^{y_t} U(y)\, dy \tag{2.8.2}$$

which permits the evaluation of f by equation (2.8.1). If y_a is defined such that $U_a = U(y_a)$ and defining the ratios a and b as

$$a = \frac{y_a}{y_t} \qquad b = \frac{\delta}{y_t} \tag{2.8.3}$$

equation (2.4.9) may be evaluated at y_a resulting in

$$\frac{U_a}{U_*} = \frac{1}{\kappa} \ell n(\frac{y_t}{k}) + \frac{1}{\kappa} \ell n(a) + A - B + \frac{\Pi}{\kappa} \omega(\frac{a}{b}) \tag{2.8.4}$$

and from eq.(2.8.1)

$$\frac{1}{\sqrt{f}} = \frac{1}{\sqrt{8}\, \kappa} \ell n(\frac{y_t}{k}) + D \tag{2.8.5}$$

where the new parameter D is computed from

$$D = \frac{1}{\sqrt{8}} \left[\frac{1}{\kappa} \ell n(a) + A - B + \frac{\Pi}{\kappa} \omega(\frac{a}{b}) \right] \tag{2.8.6}$$

It can be seen that the shape of the wake modifies the intercept but not the slope in a log- inverse-square-root graph of f related to y_t.

CHAPTER 3

MEASUREMENTS AND AUTOMATED ANALYSIS RESULTS

3.1 Survey of conducted experiments

A total of 70 experiments were conducted in the laboratory flume described in section 1.2. The first 12 experiments were conducted while developing the program VELMEAS mainly to assess the various measuring devices and the program's data acquisition and analysis routines. Experiments # 13 to # 32 were done with the "smooth" bed formed by the painted steel-sheet of the flume bottom, and experiments # 33 to # 70 to the rough bed formed by lead balls. All experiments consisted of the measurement of the vertical distribution of velocities at the flume axis in a fixed section, with the exception of experiments # 27 to # 32, which measured horizontal distribution of velocities at approximately 80 % and 20 % of the flow depth.

After the initial tests, it was decided to mantain the depth at approximately one tenth of the width to minimize wall effects. This was also compatible with the requirement of establishing a uniform flow. The discharge was then varied from experiment to experiment in the range allowed by the installation, and the depth and slope modified accordingly to obtain a well-defined uniform flow with minimal pertubations. In the case of the packed-ball bed the depth was defined as the vertical distance between the water surface and the ball top. Measurements were also refered from the ball top.

A failure in the analog-to-digital converter was particular annoying because it was present at first for certain range of frequencies only. Later it extended to the whole range of frequencies. By inspecting the PDF diagram it was found that experiments 1 to 16 should be discarded, but this problem demostrated the uselfuness of the PDF in assessing the readiness of the entire system.

Table 3.1 in the next three pages contains a listing of conducted experiments, with indication of the water temperature, the depth, the discharge and the slope. Appendix D contains the same information as originally stated by the operator (and subsequently used by the program VELMEAS for the wall-correction procedure) in different units.

The following notes refer to observations in Table 3.1 succeeding.

(1): Original smooth bed of steel sheet.

(2): Smoother painted steel sheet

(3): Lost measurements because damage in Analog-to-digital signal converter.

(4): Horizontal velocity profile measurements. The position y is given in mm. in each of two levels corresponding to same flow conditions.

(5): Same as in (4)

(6): Same as in (4)

(7): Rough bed formed by laying a packed layer of lead balls.

(8): Lost measurements because of troubles during operation.

(9): These are part of a same profile. Later unified in file sea6036.

(10): Conditions in the upper stilling basin too rough (discharge too high).

(11): These are part of a same profile. Later unified in file sea6067.

Table 3.1 : Survey of experiments

Experiment number (filename)	Temperature T Celsius D.	Depth y_t mm.	Discharge Q m3/s.	Slope S	Observations
1 to 9					(1) (3)
10 to 12					(2) (3)
13 (sea6001)	22.0	52.07	0.01281	0.00115	(2) (3)
14 (sea6002)	21.0	59.44	0.01455	0.00105	(2) (3)
15 (sea6003)	27.0	57.91	0.01446	0.00125	(2) (3)
16 (sea6004)	28.0	63.75	0.01607	0.001025	(2) (3)
17 (sea6005)	28.2	62.23	0.01603	0.00115	(2)
18 (sea6006)	27.5	63.25	0.01611	0.00110	(2)
19 (sea6007)	23.5	63.75	0.01760	0.00120	(2)
20 (sea6008)	24.5	63.25	0.01764	0.00140	(2)
21 (sea6009)	26.0	61.47	0.01433	0.00100	(2)
22 (sea6022)	26.8	60.71	0.01436	0.00105	(2)
23 (sea6023)	26.8	54.86	0.01240	0.00100	(2)
24 (sea6024)	26.6	54.36	0.01242	0.00110	(2)
25 (sea6025)	25.6	54.86	0.01019	0.00075	(2)
26 (sea6026)	26.2	54.36	0.01013	0.00075	(2)
27 (sea6027)	21.2	61.21	0.01458	0.00100	(2) (4) y=12.2
28 (sea6028)	28.4	60.96	0.01460	0.00100	(2) (4) y=49.0
29 (sea6029)	27.4	54.10	0.01000	0.00085	(2) (5) y=10.82
30 (sea6030)	25.7	54.10	0.01000	0.00085	(2) (5) y=43.28

Table 3.1 : Survey of experiments (continued)

Experiment number (filename)	Temperature T Celsius D.	Depth y_t mm.	Discharge Q m3/s.	Slope S	Observations
31 (sea6031)	26.2	58.17	0.01762	0.00155	(2) (6) y=11.63
32 (sea6032)	21.8	58.17	0.01760	0.00175	(2) (6) y=46.53
33 (sea6033)	28.9	63.25	0.01181	0.00165	(7) (8)
34 (sea6034)	30.0	63.25	0.01192	0.00165	(7)
35 (sea6035)	30.75	64.26	0.01208	0.00150	(7)
36 (sea6036)	25.25	63.12	0.00719	0.00045	(7) (9)
37 (sea6037)	25.25	63.12	0.00719	0.00045	(7) (9)
38 (sea6038)	29.5	62.99	0.00719	0.00045	(7)
39 (sea6039)	30.0	62.99	0.01016	0.00100	(7)
40 (sea6040)	30.0	62.74	0.01016	0.00110	(7)
41 (sea6041)	29.0	64.01	0.01437	?	(7) (8)
42 (sea6042)	29.95	64.52	0.01437	0.00210	(7) (8)
43 (sea6043)	28.0	63.88	0.01437	0.00205	(7)
44 (sea6044)	29.4	63.88	0.01437	0.00205	(7)
45 (sea6045)	29.75	63.63	0.01607	0.00260	(7)
46 (sea6046)	29.9	63.37	0.01607	0.00250	(7)
47 (sea6047)	28.95	63.63	0.01760	0.00295	(7)
48 (sea6048)	30.0	63.63	0.01760	0.00300	(7)
49 (sea6049)	30.1	64.77	0.01901	0.00335	(7)
50 (sea6050)	30.95	64.90	0.01901	0.00330	(7)

Table 3.1 : Survey of experiments (continued)

Experiment number (filename)	Temperature T Celsius D.	Depth y_t mm.	Discharge Q m3/s.	Slope S	Observations
51 (sea6051)	30.05	2.545	0.02033	0.003775	(7) (10)
52 (sea6052)	31.0	2.545	0.02033	0.003775	(7) (10)
53 (sea6053)	29.9	2.48	0.00719	0.00050	(7)
54 (sea6054)	29.9	2.51	0.00719	0.000475	(7)
55 (sea6055)	30.2	2.51	0.01016	0.00095	(7)
56 (sea6056)	30.45	2.505	0.01016	0.00095	(7)
57 (sea6057)	28.5	2.51	0.01245	0.001575	(7)
58 (sea6058)	31.0	2.50	0.01245	0.00160	(7)
59 (sea6059)	31.0	2.51	0.01437	0.002025	(7)
60 (sea6060)	31.0	2.520	0.01437	0.00200	(7) (8)
61 (sea6061)	30.95	2.49	0.01437	0.00205	(7)
62 (sea6062)	29.6	2.48	0.01607	0.00265	(7) (8)
63 (sea6063)	30.1	2.485	0.01607	0.002575	(7)
64 (sea6064)	29.0	2.51	0.01760	0.00295	(7)
65 (sea6065)	30.55	2.505	0.01760	0.00300	(7)
66 (sea6066)	31.0	2.495	0.01901	0.00335	(7)
67 (sea6067)	30.55	2.51	0.01901	0.003375	(7) (11)
68 (sea6068)	30.55	2.51	0.01901	0.003375	(7) (11)
69 (sea6069)	30.75	2.53	0.02033	0.00380	(7)
70 (sea6070)	29.25	2.53	0.02033	0.00385	(7)

3.2. Analysis of Results

Results obtained from two similar cases, #17 and #18 (see Table 3.1) exhibit difficulties typically found in these kind of measurements. Values obtained closest to the bottom are bound to greater measurement uncertainties and errors that those relatively far from the bed. Figure 3.1 corresponding to case #17 documents the search for the virtual origin using an increasing number of points from the bottom. Points symbolized by a square correspond to the original set of values referred to the reference bottom (in this case the steel sheet forming the bed) after bottom proximity and wall corrections and filtering (theory seen in Chapter 2, program implementation in Chapter 4). Each search is indicated with a different symbol as indicated in top left of the graph. In figure 3.1 it is clear that the closest-to-the-bed point is too deviated to the left. As a result, the first search, conducted with only 4 points and symbolized with a circle, find the best linear regression for an excessively large $\epsilon+$ of 184.731 (also indicated in the graph as E+), which should be compared with the other values of $\epsilon+$ found for searches with 5 up to 10 points in the same graph, with ϵ^+ ranging between 35 and 55.

The linear regression moves consequently and excessively to the right, and then the Karman coefficient (indicated as VK in the graph) becomes a small κ of 0.164, while A′ (See equation 2.4.14; indicated as AP in the graph) becomes a large value of -19.2. Including more points rapidly compensates the influence of the first point, although does not eliminate it. The Case #18, corresponding to figure 3.2 exhibits the opposite case, since the first point is deviated to the right. The Karman coefficient for the best linear regression result overestimated in this case, in contrast to previous case.

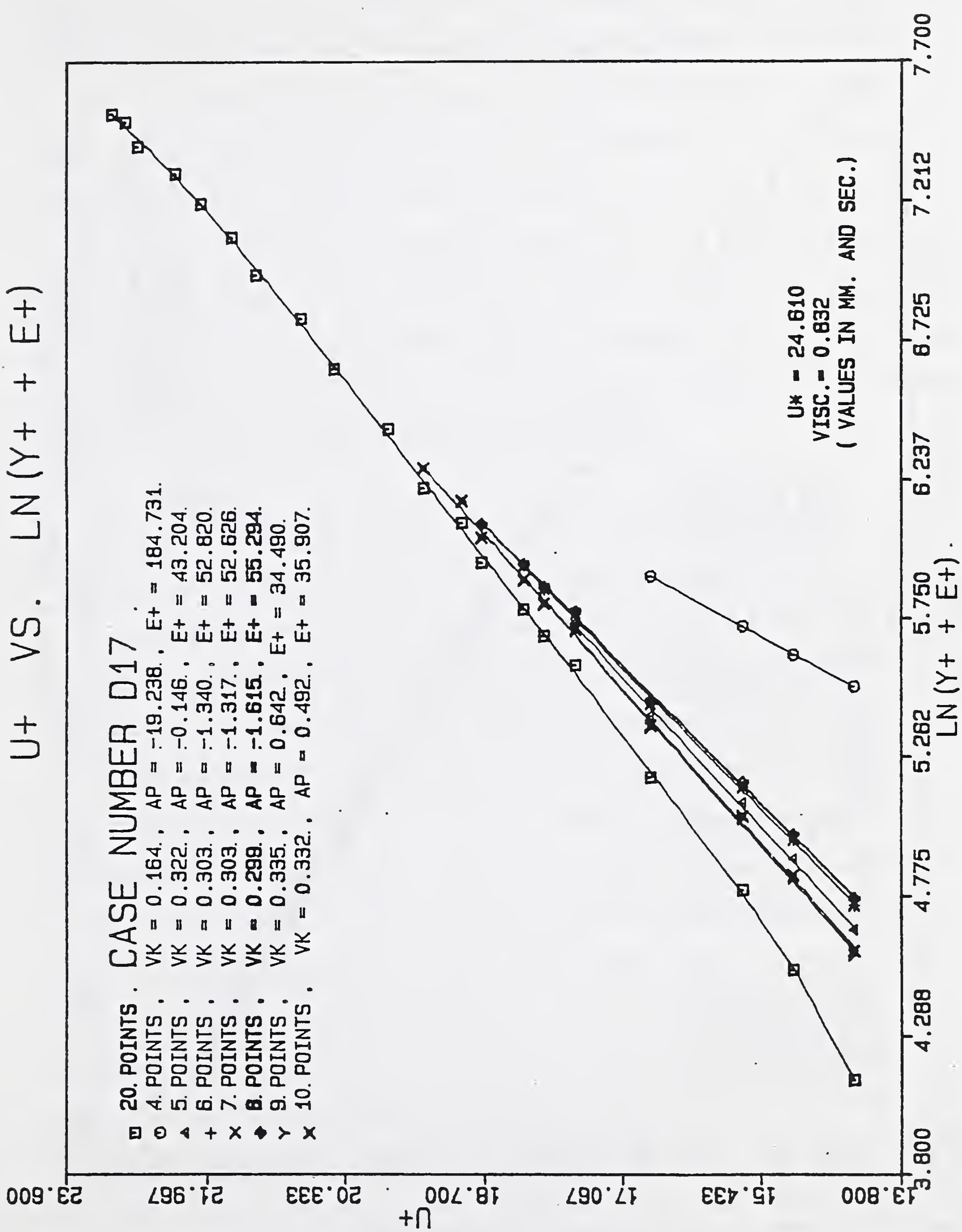


Figure 3.1 : Virtual-origin search. Case number 17.

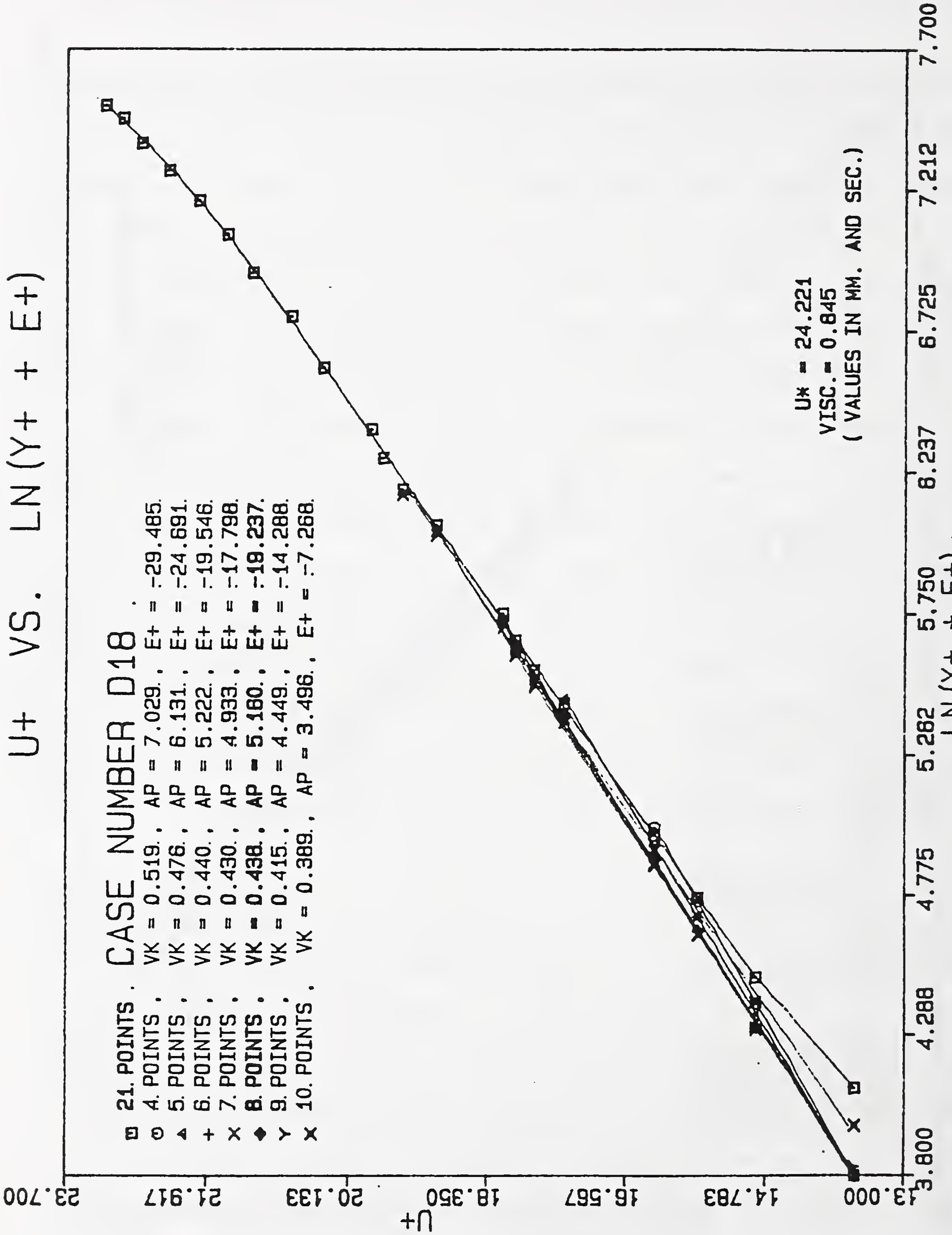


Figure 3.2 : Virtual-origin search. Case number 18.

The sensitivity of the parameters to measurement errors handicaps the procedure for use with data obtained with simple equipment, as in this case, but should be more valuable when applied to LDA obtained data. At the same time, errors like the present in both cases #17 and #18 are not masked by the procedure but are, on the contrary, emphasized, which constitutes a reassurance for any conclusion the analysis may lead to. As will be demonstrated in subsequent analyses, the procedure serves in fact to establish the quality of the data in its whole extent, and in consequence the reliability of results drawn from its analysis. In this sense, it may serve as a standard procedure to judge velocity distribution data quality.

Case #19 appears not to exhibit the problem found in the previous cases. Figures 3.3, 3.4 and 3.5 display the same analysis repeated from 4 points up to 21, the total number of points measured. Figures 3.4 and 3.5 include entirely all misleading searchs, since the wake is clearly included in the distributions. Nevertheless, continuing the analysis up to the last point serves the purpose of confirming the presence of inner and outer zones. In fact, when resulting parameters from the virtual searchs are plotted against the logarithm of the ratio H/δ, being H the layer thickness covered by each search, as in Figure 3.6 for the case #19, those parameters vary slowly (after regression analysis) in the inner layer, while changing rapidly (without physical meaning however) in the outer layer. The apparent smoothness of the data is decreased in Figure 3.6 because the high sensitivity of the procedure much amplifies data errors, but the tendency is clear. The third point (Fig.3.6) in particular, which corresponds to the inclusion of the 6th data point, exhibits the largest deviations. The inclusion of the 7th data point corrects it, because those two points have

also reversed and largest deviation from the original polynomial regression (see figure 3.5). The procedure is merely amplifying these underlying errors. The better the original data set fits a smooth regression, the better the virtual-origin-search-obtained regressions against H/δ would be.

Figure 3.7 show distributions obtained for the same case #19 by using a null virtual-origin. In this figure, graph a) contains the whole profile corresponding to equation (2.5.11) while graph c) is restricted to the lower 10 % of the depth. Graph b) is the velocity-defect distribution of equation (2.5.15), and graph d) displays the measured wake and corresponding predictions obtained by applying the Coles equation (2.4.6) and the Finley equation (2.4.7) respectively. The shape of the measured wake is nearly the same as that the given by the two predictors, but the Coles law performs better. The measured wake is obtained after obtaining a linear regression in graph b) which intentionally contains points in the inner region only. From that regression, the parameters indicated in the same graph are computed, in this case, $\kappa = 0.428$, $A' = A - \Delta U^+ = 4.871$ and $\Pi = 0.354$. The wake strength Π is obtained in the following way: First the logarithmic law of the wall is extended up to the point with maximum velocity; then the departure of the "actual" profile, as given by the best regression polynomial in graph a) from the velocity predicted by the logarithmic law is equated to $2\Pi/\kappa$ in accordance to equation (2.5.14). This is equivalent to applying equation (2.5.16) to obtain the value of Π, which is automatically done by the program. A similar procedure may be used in graph b), in agreement with equation (2.5.15). In this case #19, Coles law adjusts better than Finley law. The regression shown in graph c) is not necessarily the linear one. Instead, a best regression search, as measured by the standard error of

estimate has been conducted using different polynomial orders, to obtain an indication of possible presence of the wake or eventually, closer to the bed, of the buffer zone. In the displayed case, a quadratic regression was automatically selected by the program, possibly indicating the presence of the wake. This is confirmed by graph d). Hence the obtained estimation of the Karman coefficient and other parameters should be considered as biased. Nevertheless, the magnitude of the wake at those 5 points is so small that its influence in estimating those parameters is negligible, given measuring errors. The effect of a deviation in the point measured closest to the bed, already discussed for cases #17 and #18, appears even more clearly in these graphs, as in figures 3.8 and 3.9 corresponding to case #17.

Figures 3.10, 3.11 and 3.12 correspond to case #20. The original distribution contains some irregularities, particularly an unexpected convexity for values of $\ln(y^+)$ between 5.3 and 6.3 (Fig.3.10). This shows up more clearly in the measured wake (Fig.3.11) and very much disrupts the functions upon H/δ (Fig.3.12).

Similar results, although attenuated, can be observed in Figures 3.13, 3.14 and 3.15 corresponding to case #22. The shape of the measured wake in Fig.3.14.d) differs from Coles' and Finley's predictors, but the Finley law is closer to measurement, as in case #20. For experiments conducted with the "smooth" bed, neither of the two predictors was found better than the other, but for experiments conducted with the rough bed, the Finley law was consistently better than the Coles law. The best agreement, however, was found for a smooth-bed case, #26, shown in Figures 3.16, 3.17 and 3.18. Figures 3.19 and subsequent ones correspond to experiments conducted with the

rough bed formed by lead balls. Case #34 is shown in Fig. 3.19, 3.20 and 3.21. Again the first point exhibits a larger measurement error, as clearly seen in Fig.3.21. The change in shape of the wake with respect to the predictors is more clear than in smooth-bed cases. All rough-bed cases exhibited the same trend as shown in Figures 3.22 to 3.99 for the cases #36+7, #38, #40, #42, #43, #46 to #53, #55, #57 to #59, and #62 to #70.

The use of a virtual origin in the computations does provide a better definition of the logarithmic sublayer, but leaves the Karman coefficient and the intercept depending upon the virtual distance ϵ. No definition of functional relationships for κ and A relative to ϵ was attempted because the present measurements appear to display two inconveniences; first, measurements were not made close enough to the bottom to guarantee the exclusion of the wake, which is essential to the procedure; second, the difficulties of accurately positioning the probe at the bottom produced small measuring point errors in the graphs, which would strongly affect any analysis of this kind. It is clear however, that the inclusion of a virtual origin produces smaller values of Karman coefficient than a classical computation with null virtual distance. As indicated, figure 3.7 and similar ones obtained with null virtual origin include the value of Karman coefficient, intercept and wake strength, computed by using points measured in the lower 10%-of-the-depth zone. Values obtained are in some cases very large, because the diameter of the probe forced a relatively large distance from the bed even for the closest point, and the wake appears to exist in this lower-10% zone. The effect is more clear for the rough-bed cases, were the wake is included in all measured points. The mere existence of a logarithmic zone (at least one point should exist) is thus put in doubt.

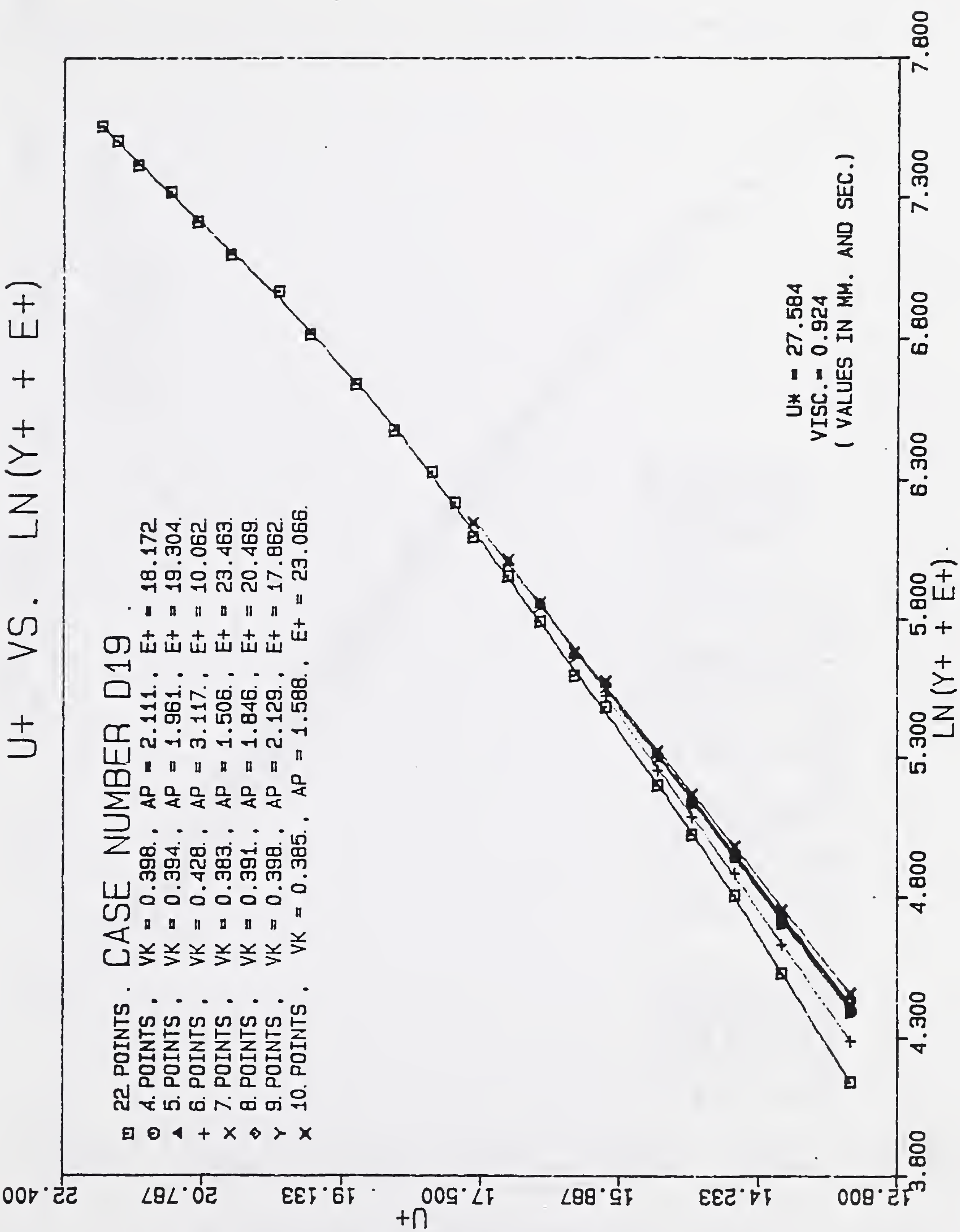


Figure 3.3 : Virtual-origin search. Case number 19.

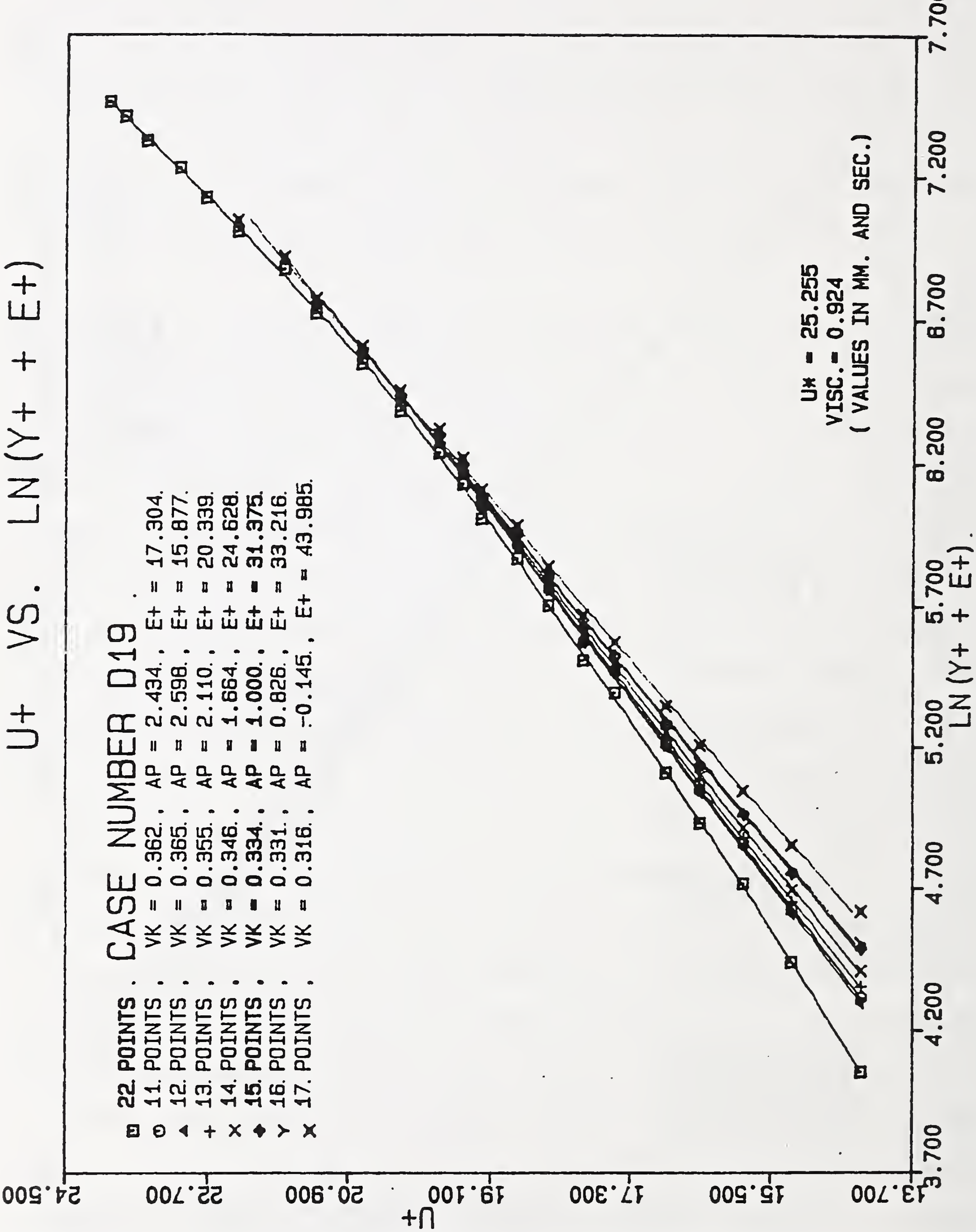


Figure 3.4 : Virtual-origin search continued. Case number 19.

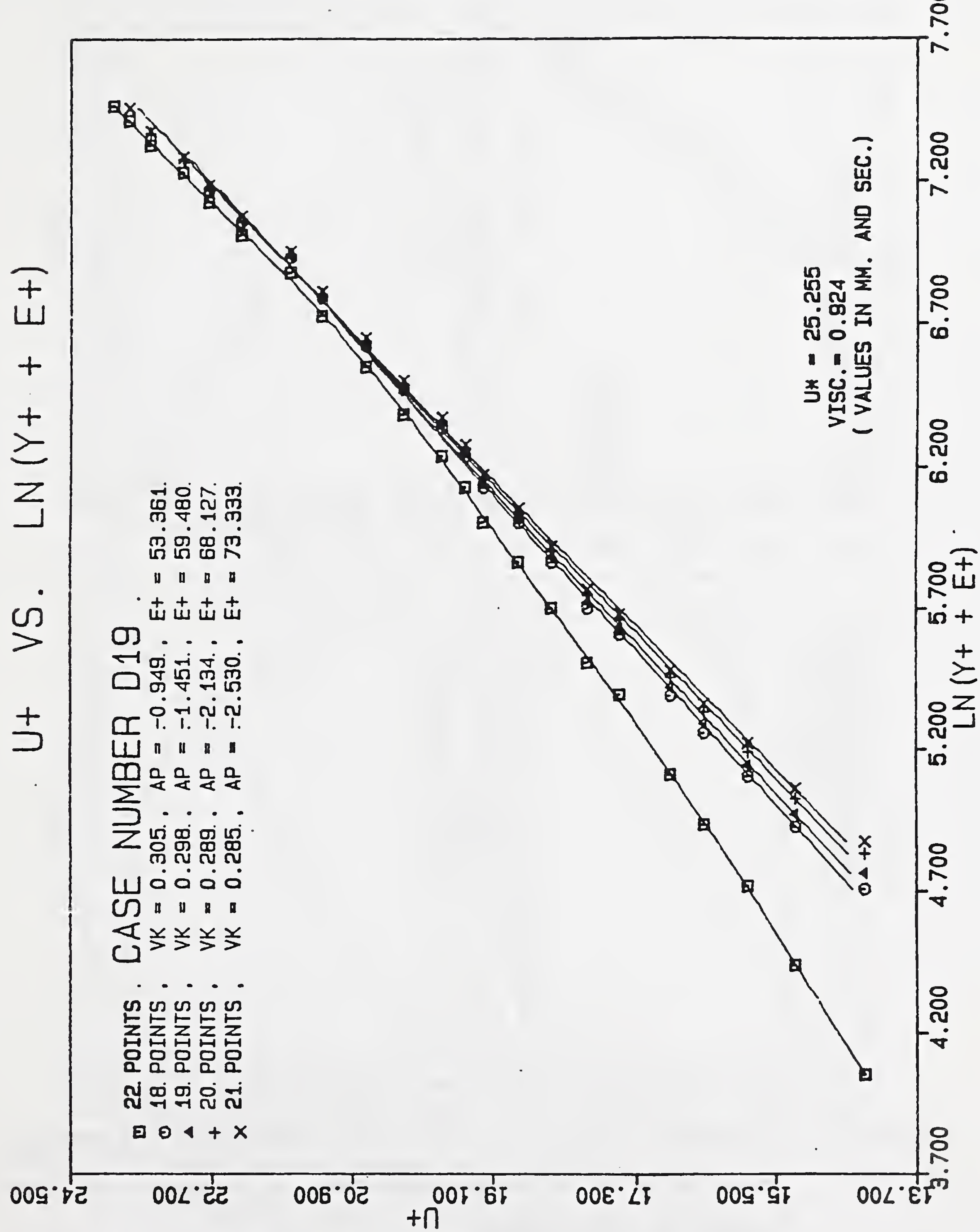


Figure 3.5 : Virtual-origin search continued. Case number 19.

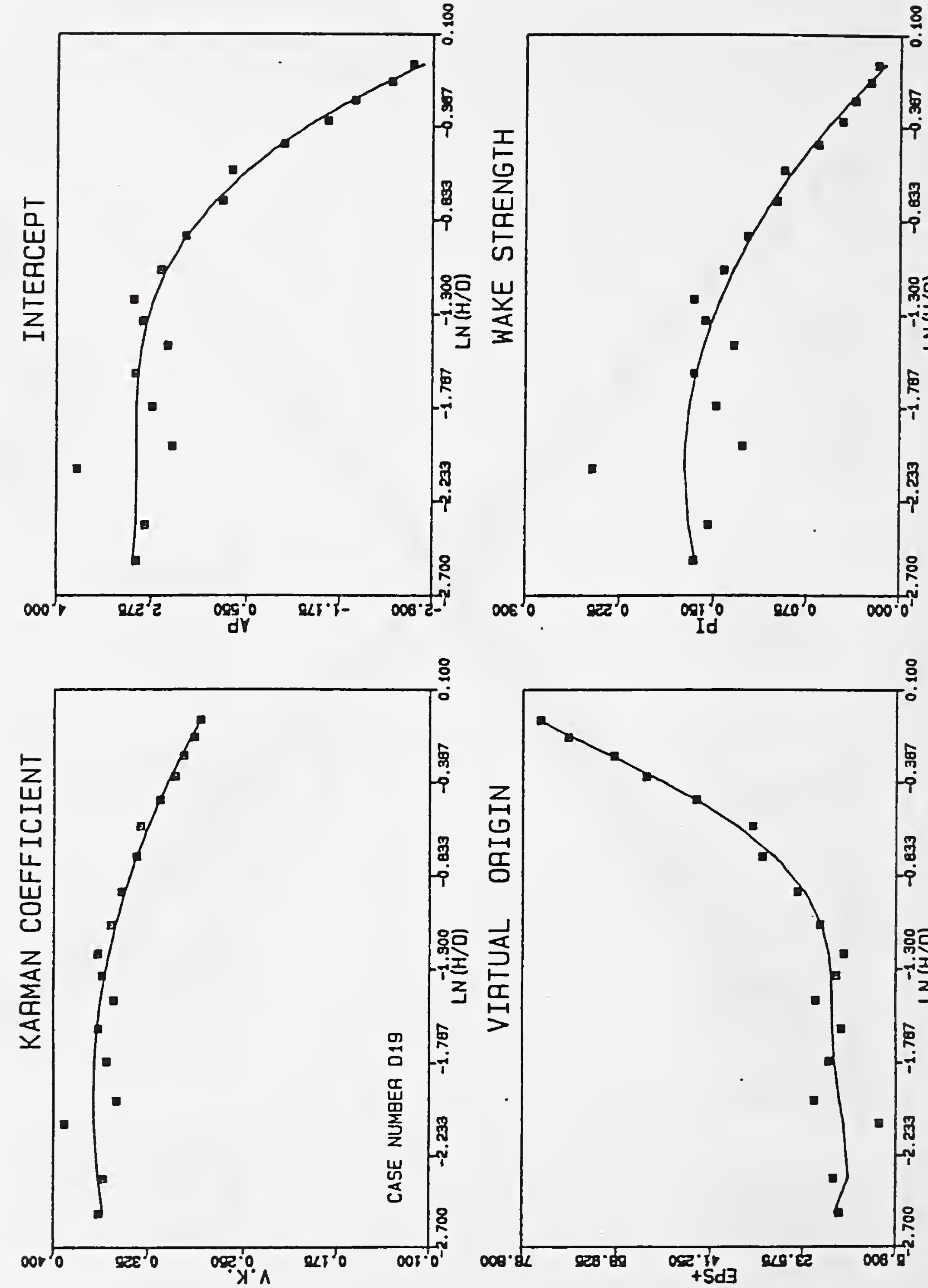


Figure 3.6 : Parameter variation with the virtual-origin-search thickness H. Case number 19. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength

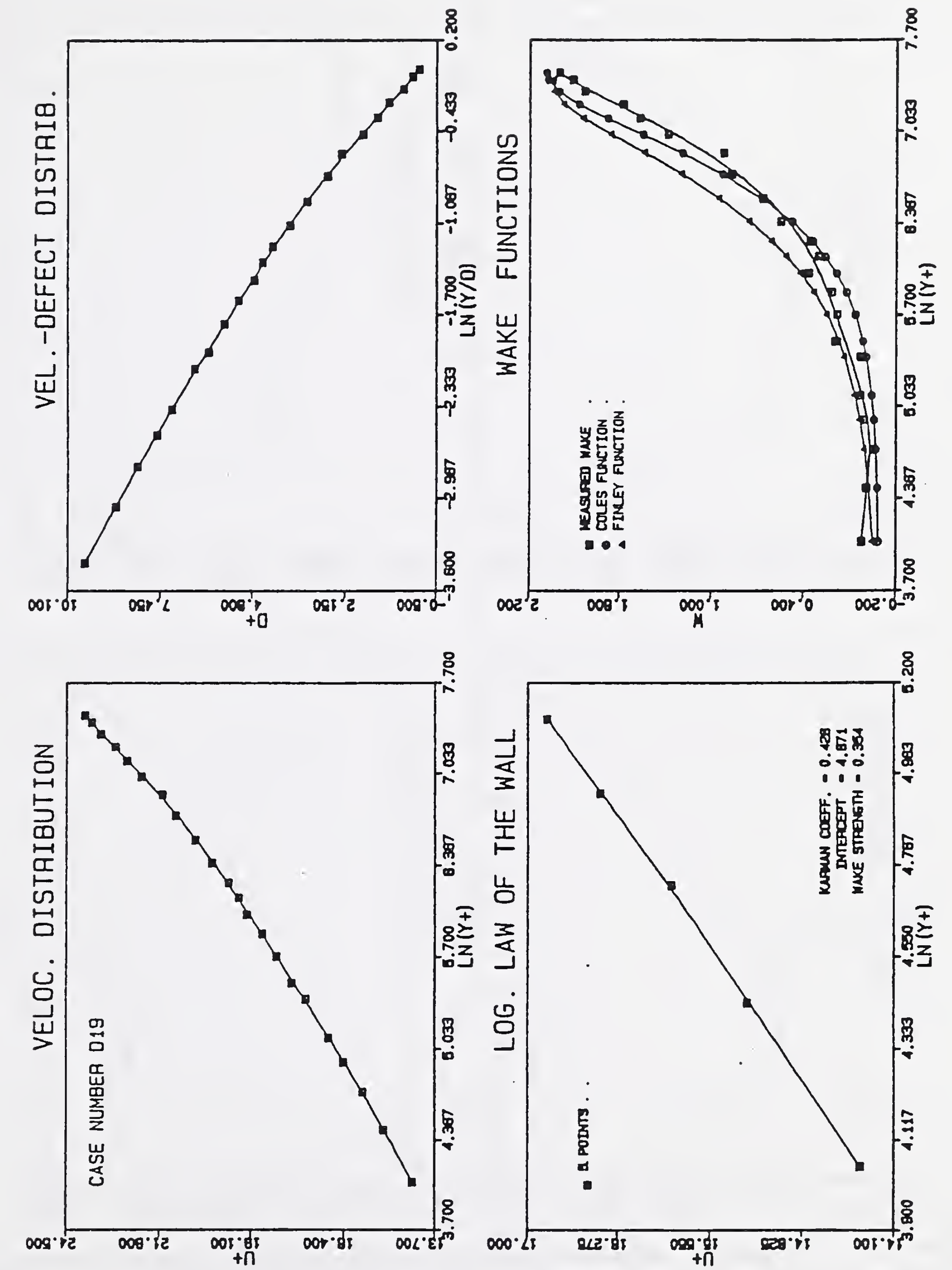


Figure 3.7 : Distributions assuming null virtual origin. Case number 19.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

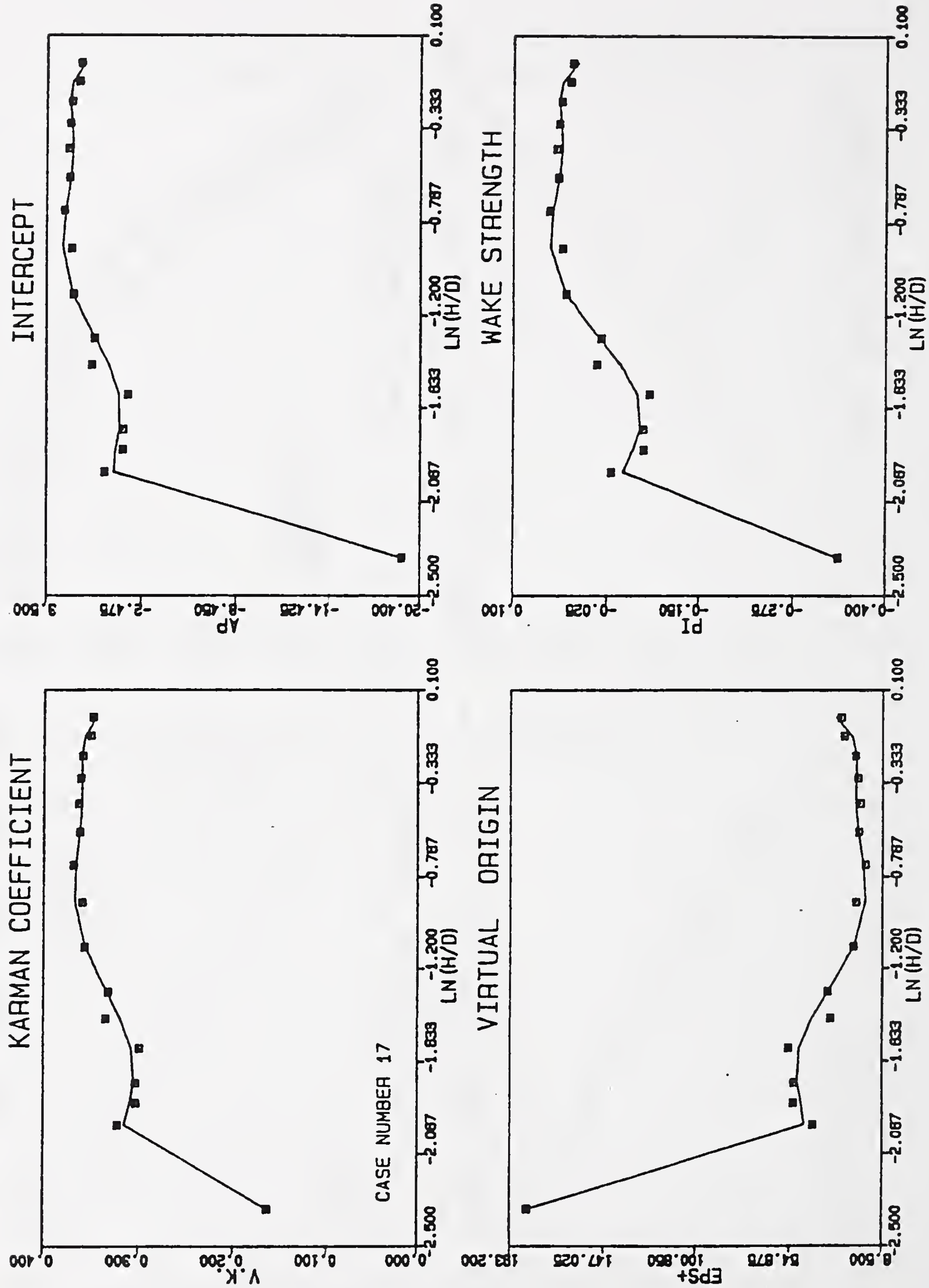


Figure 3.8 : Parameter variation with the virtual-origin-search thickness H. Case number 17. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength

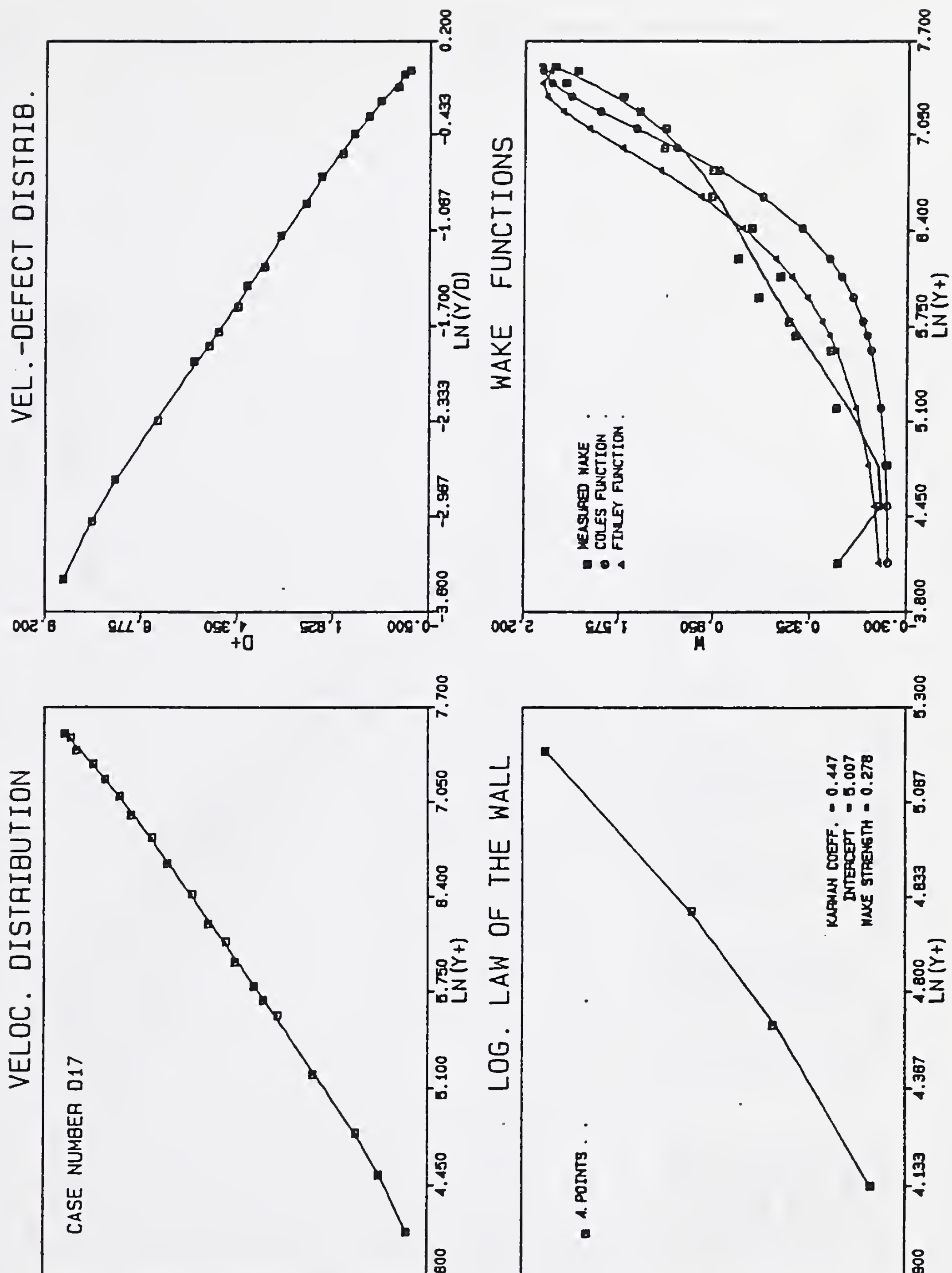


Figure 3.9 : Distributions assuming null virtual origin. Case number 17.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

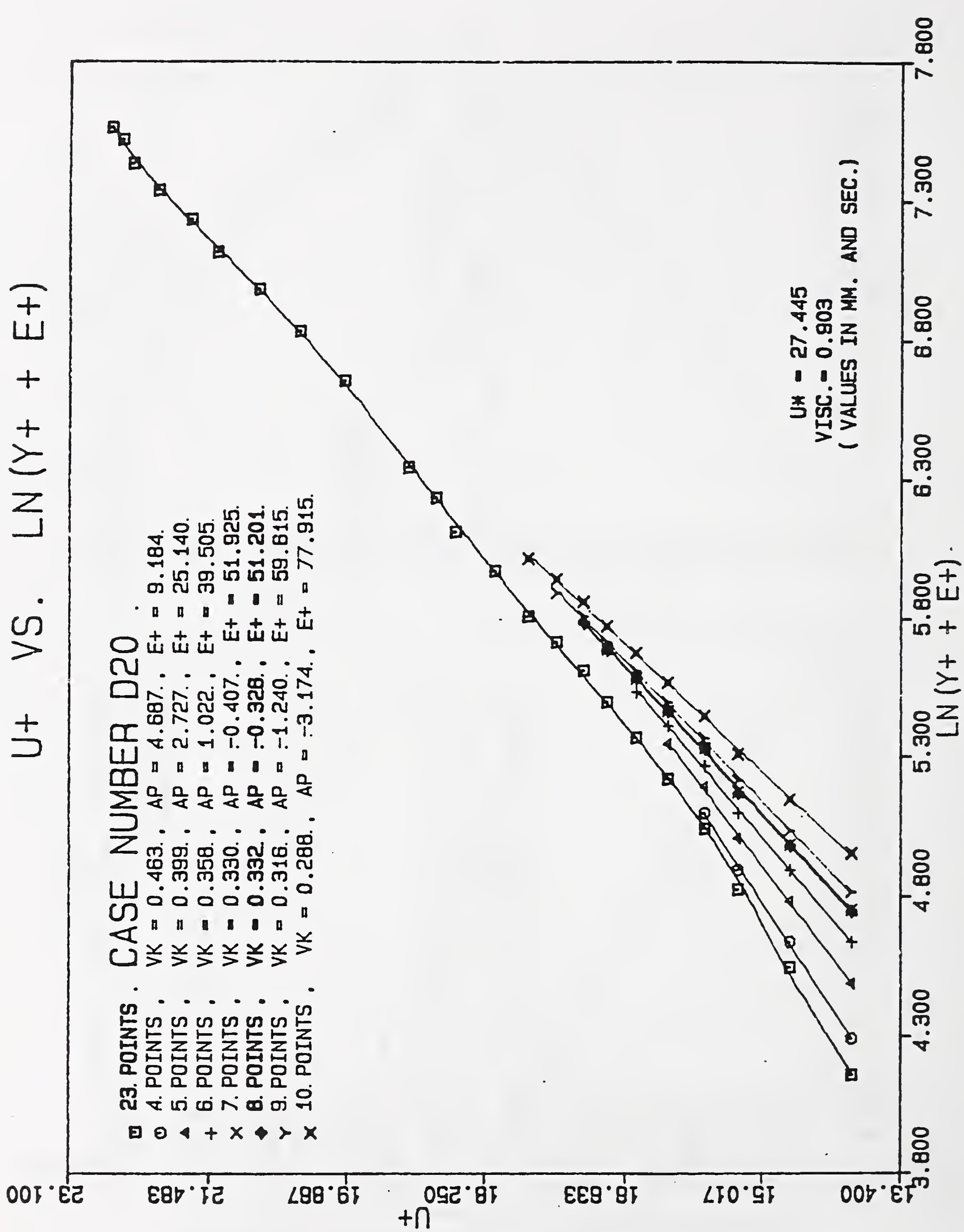


Figure 3.10 : Virtual-origin search. Case number 20.

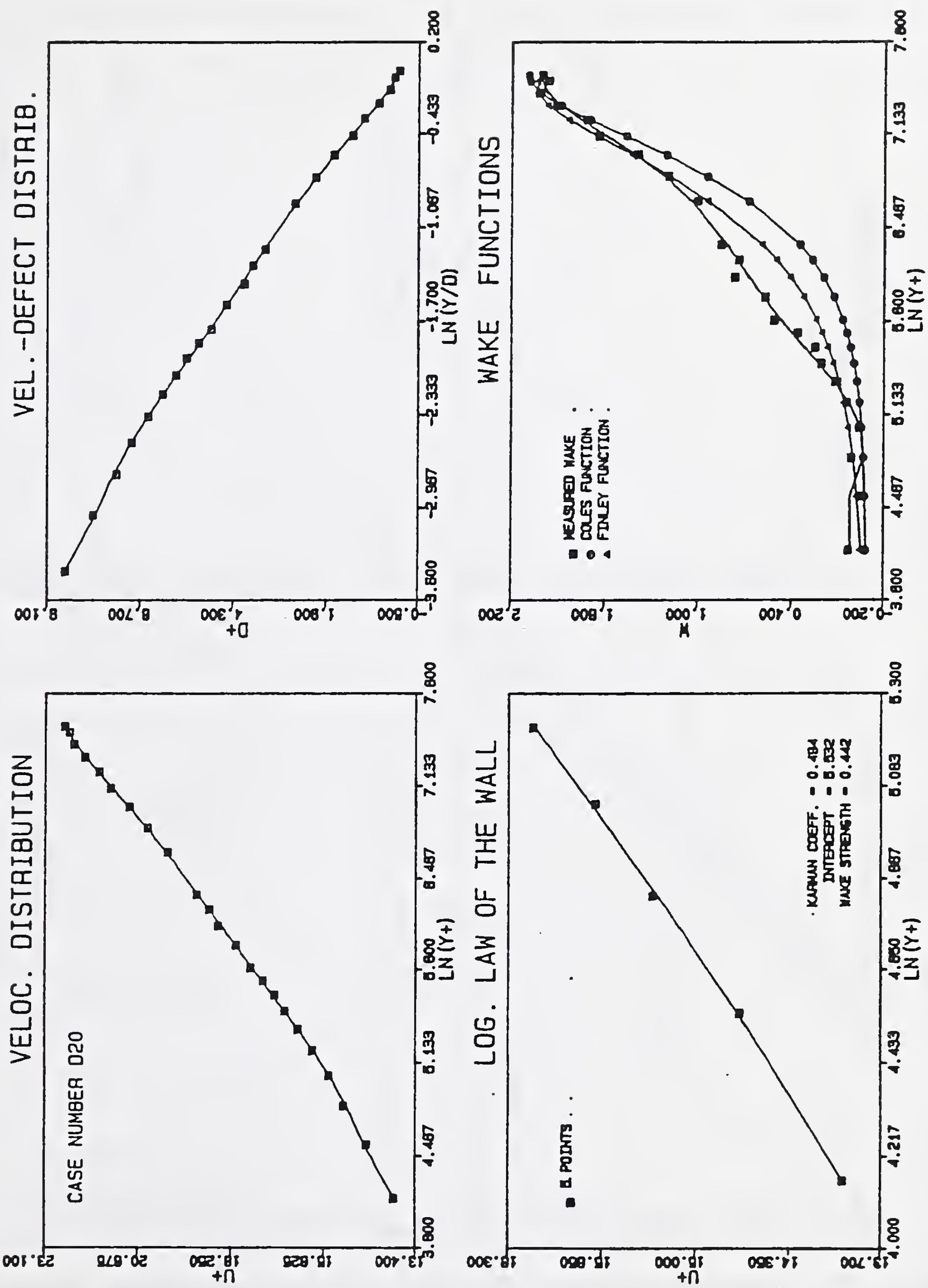


Figure 3.11: Distributions assuming null virtual origin. Case number 20.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

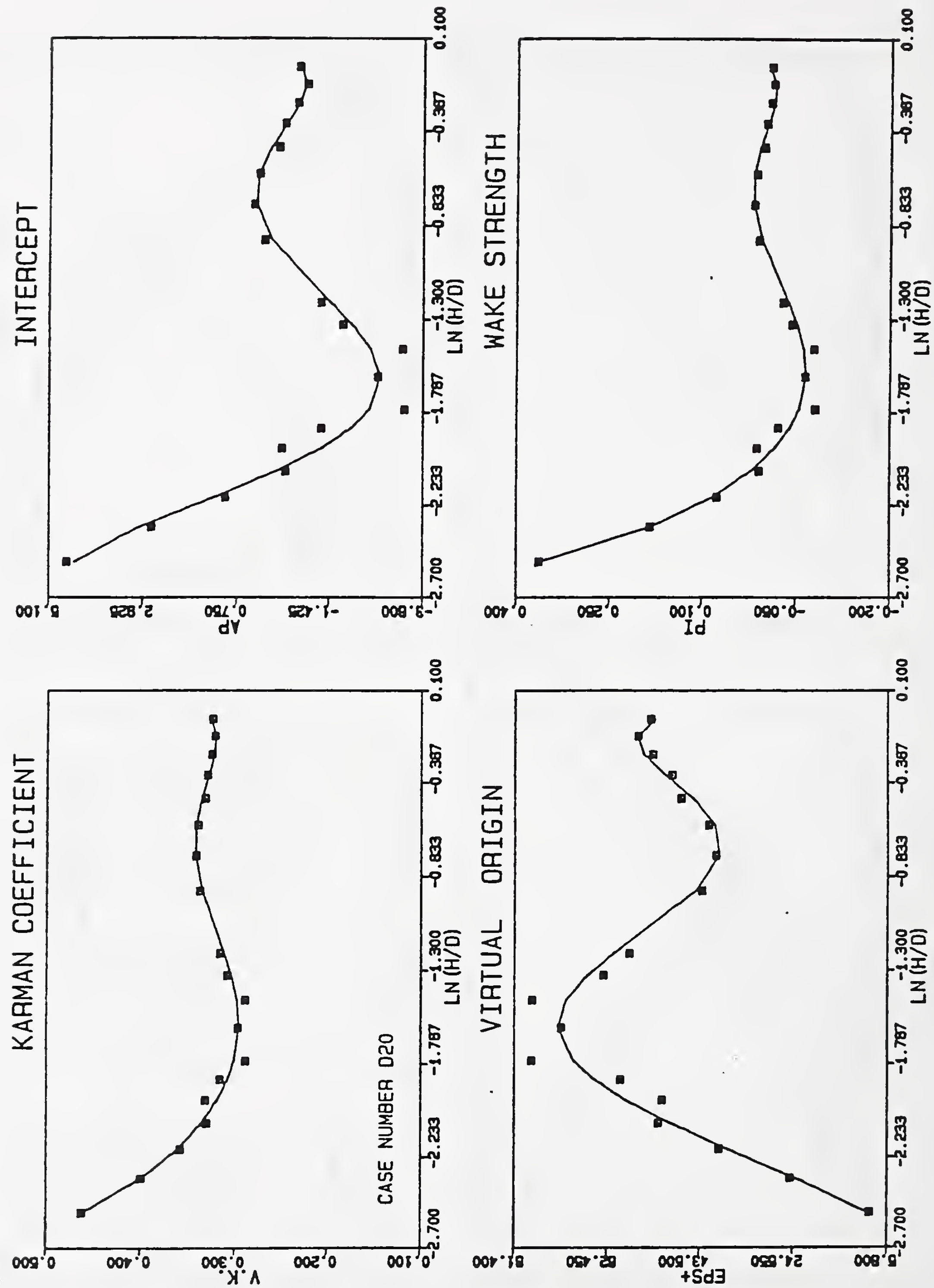


Figure 3.12: Parameter variation with the virtual-origin-search thickness H. Case number 20. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

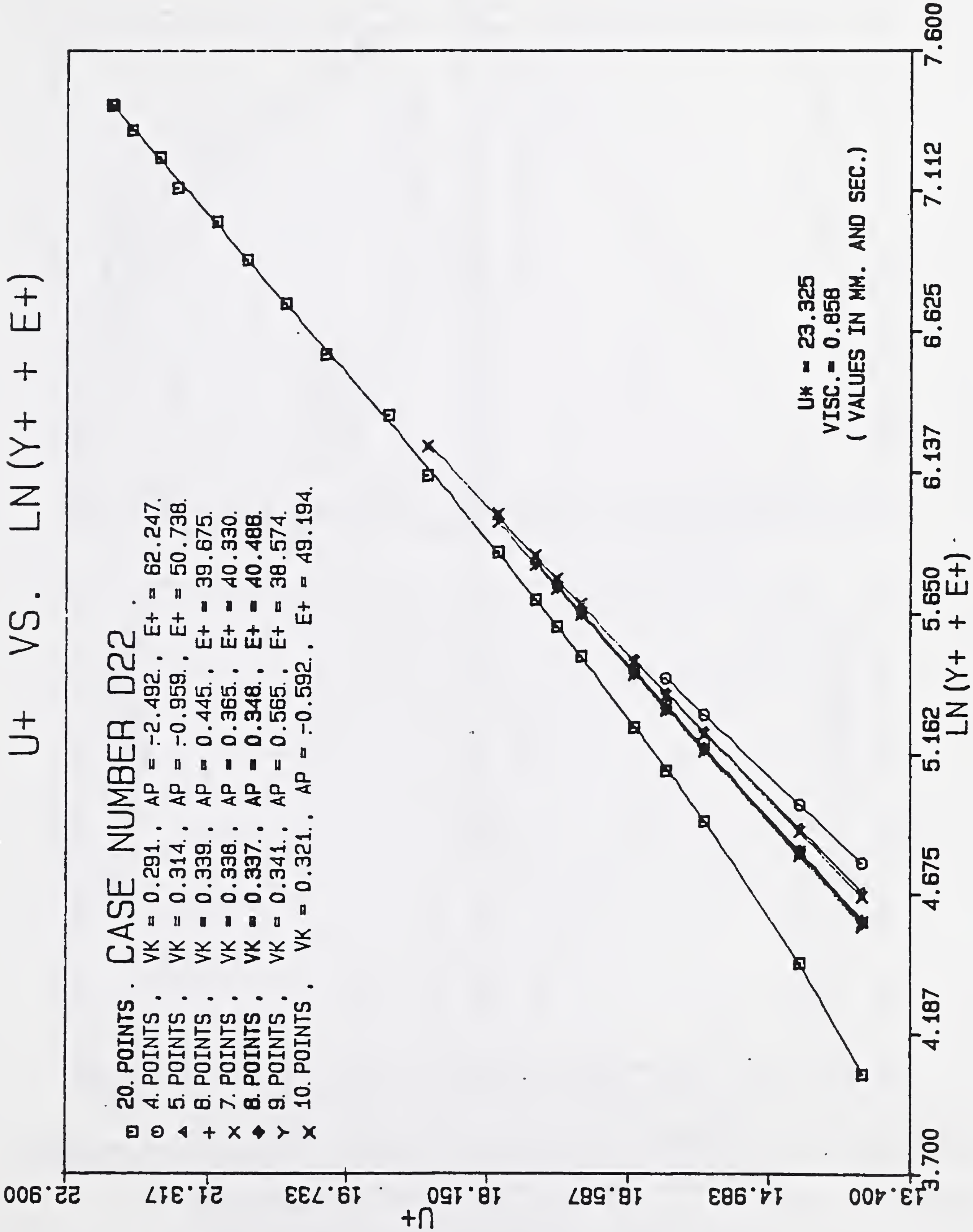


Figure 3.13 : Virtual-origin search. Case number 22.

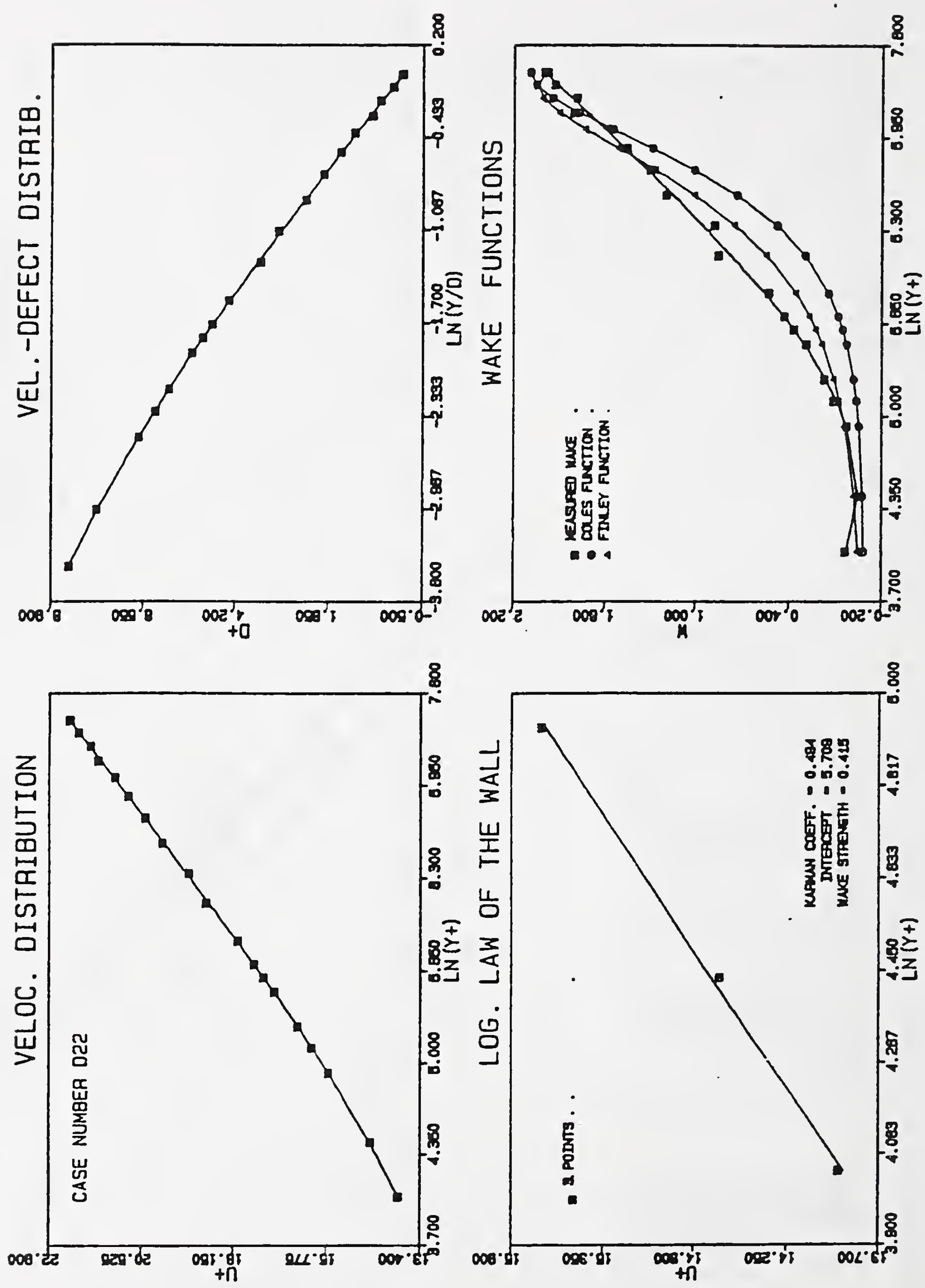


Figure 3.14: Distributions assuming null virtual origin. Case number 22.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

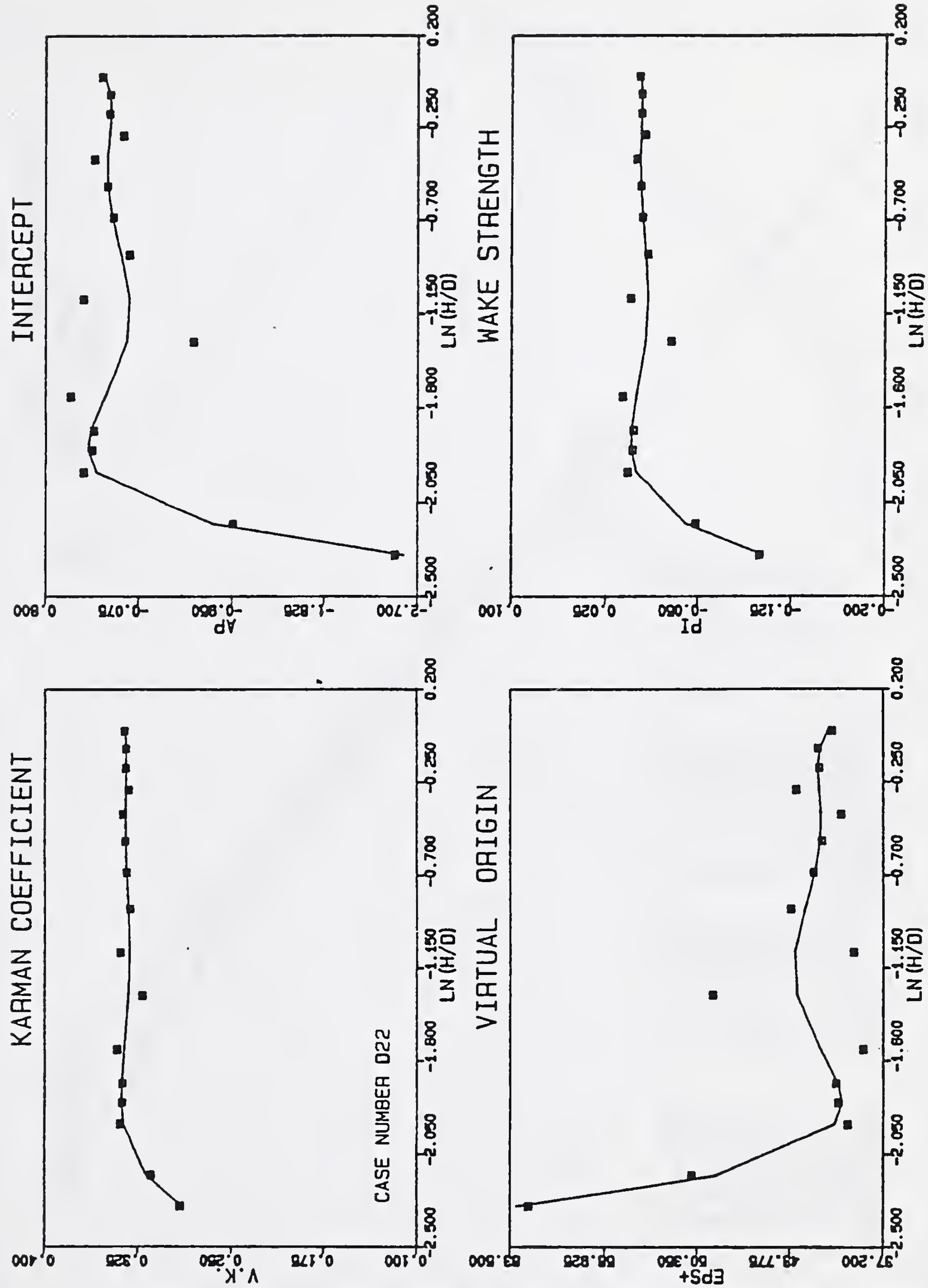


Figure 3.15: Parameter variation with the virtual-origin-search thickness H. Case number 22. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

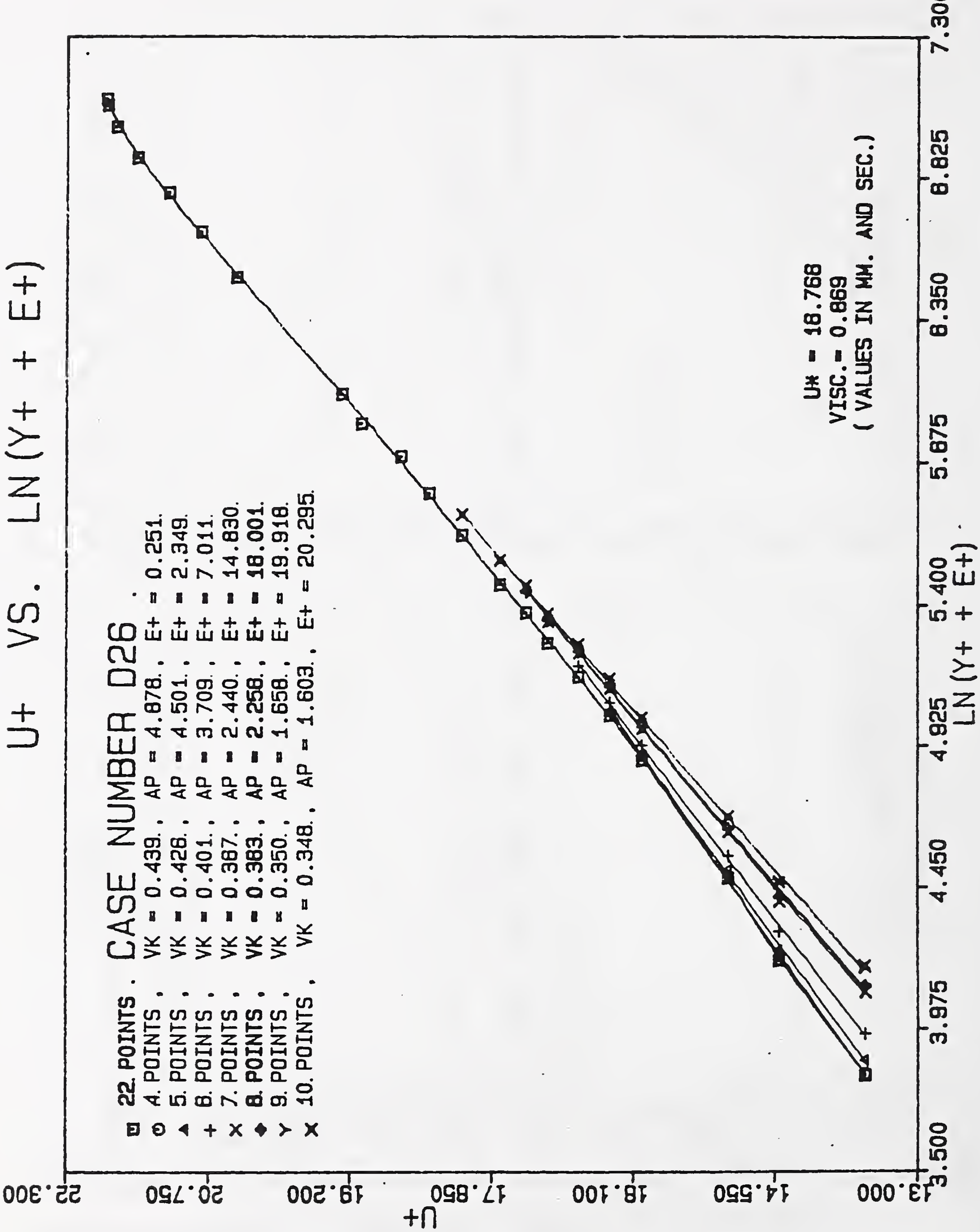


Figure 3.16 : Virtual-origin search. Case number 26.

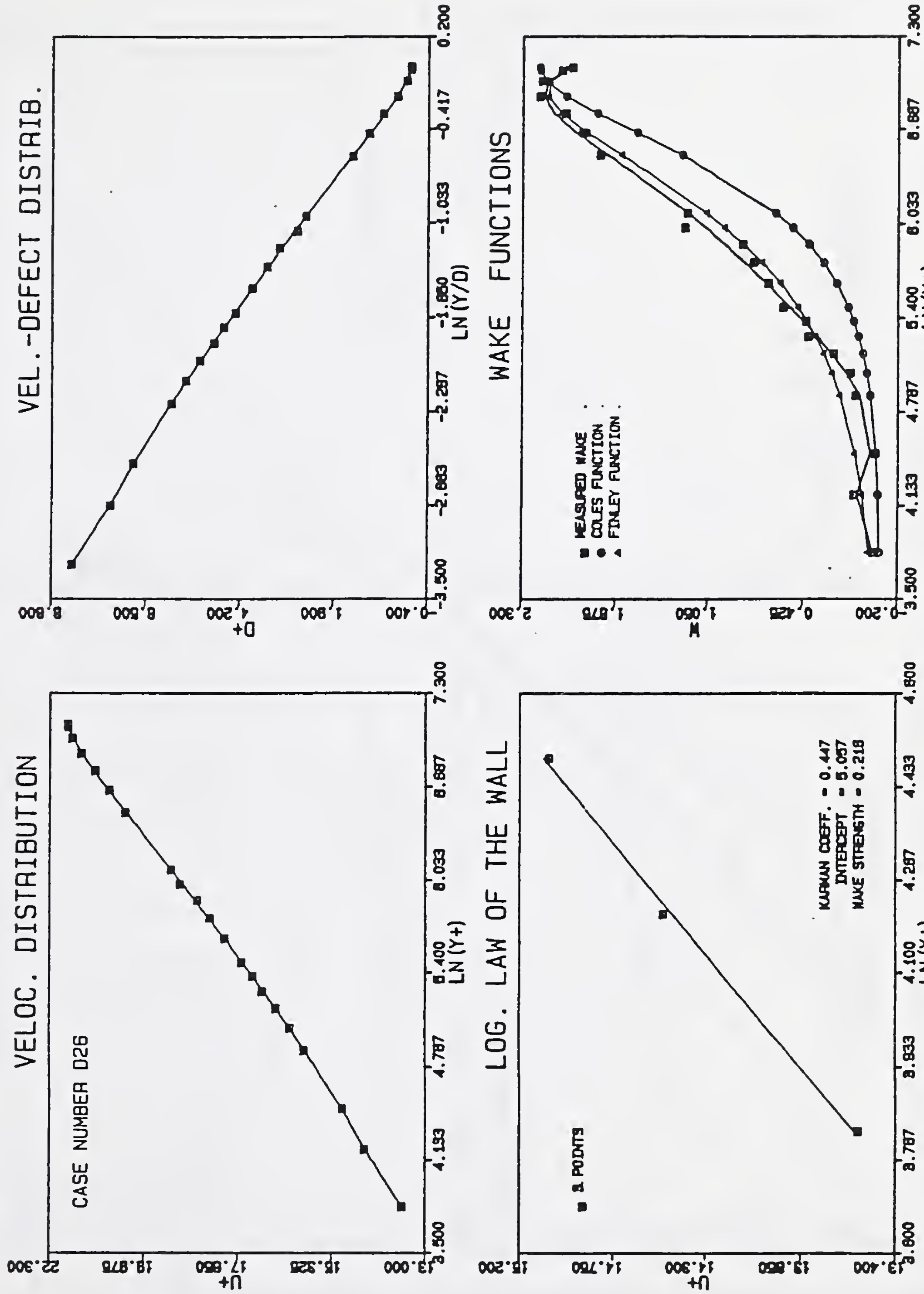


Figure 3.17: Distributions assuming null virtual origin. Case number 26.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

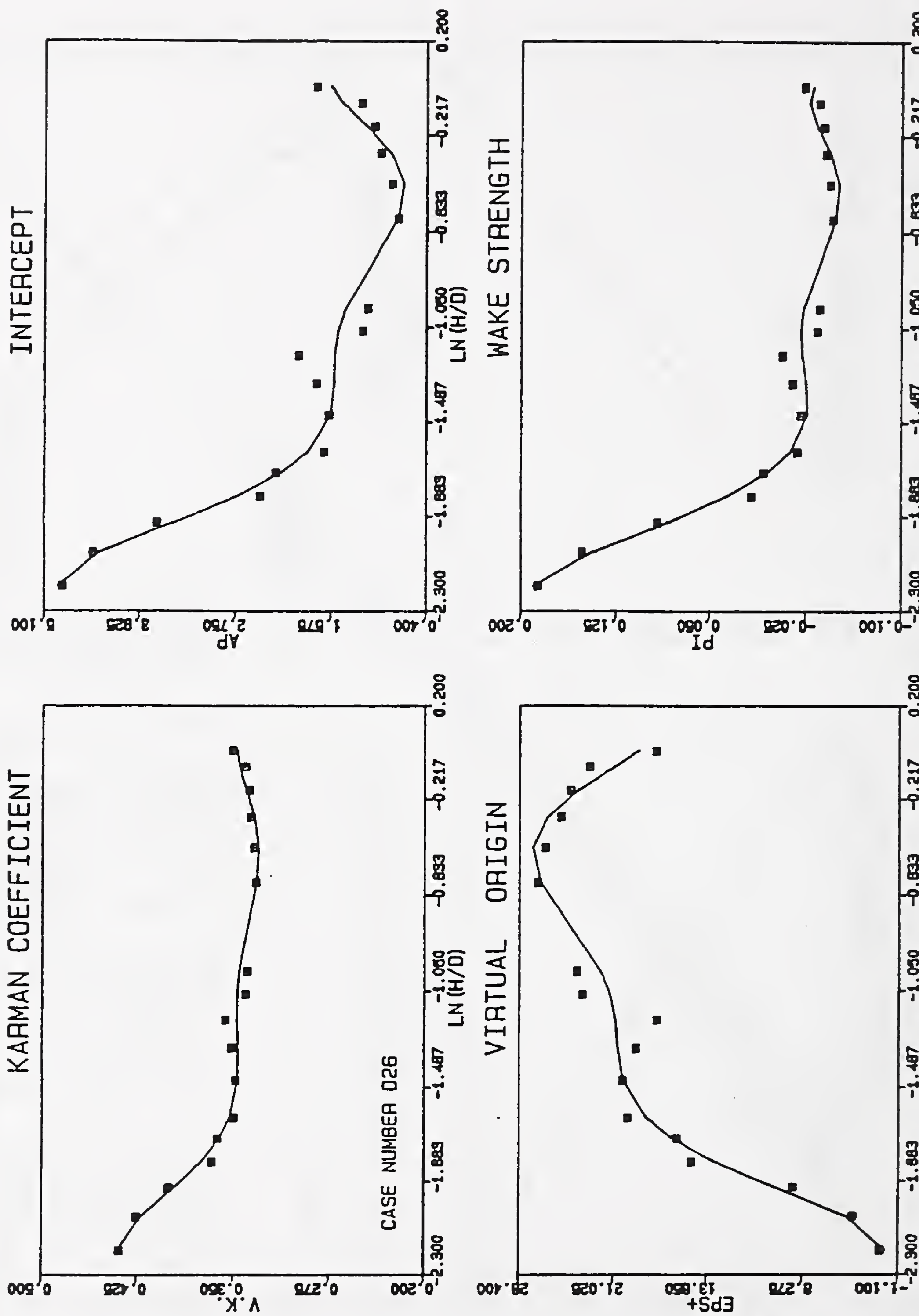


Figure 3.18: Parameter variation with the virtual-origin-search thickness H. Case number 26. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

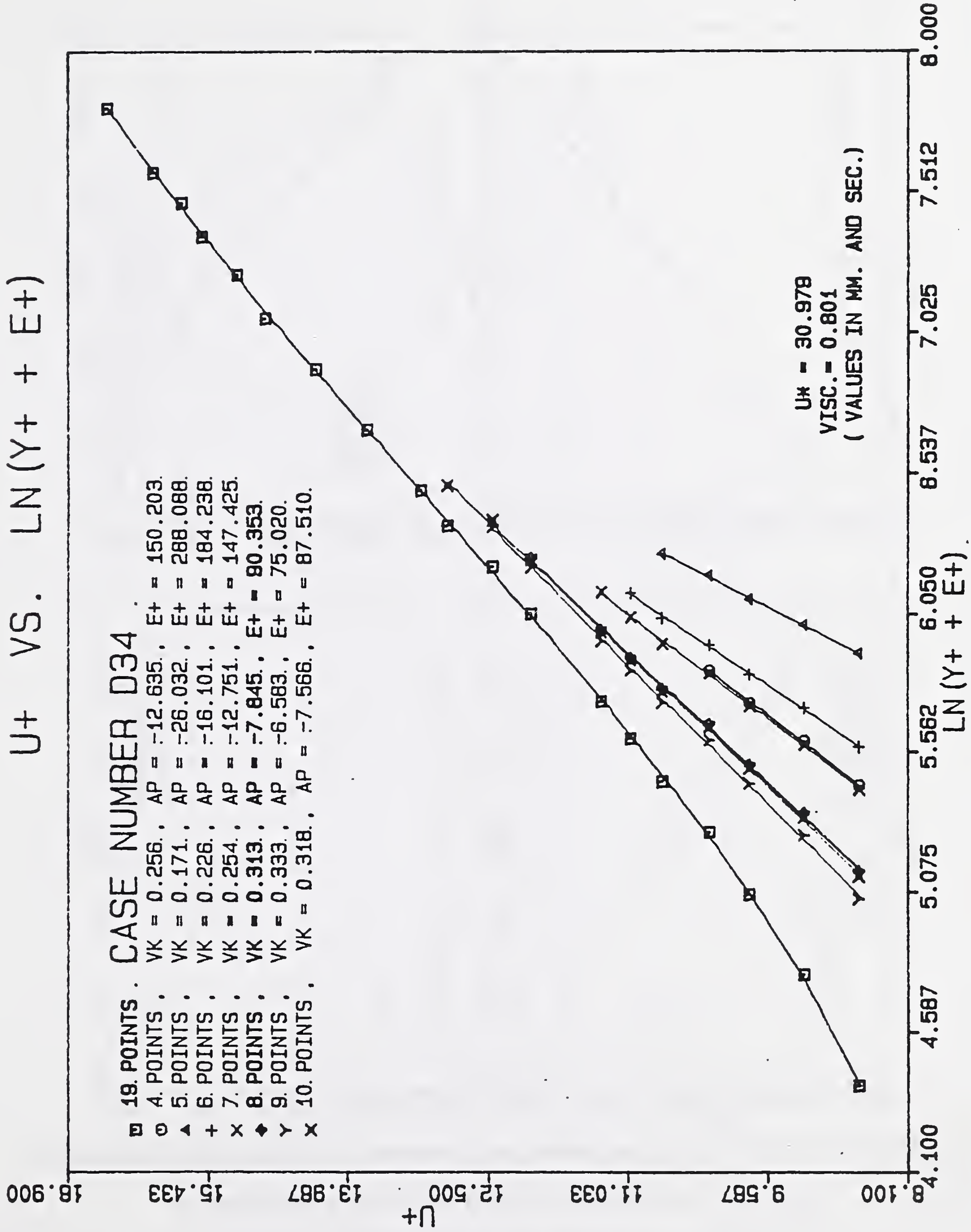


Figure 3.19 : Virtual-origin search. Case number 34.

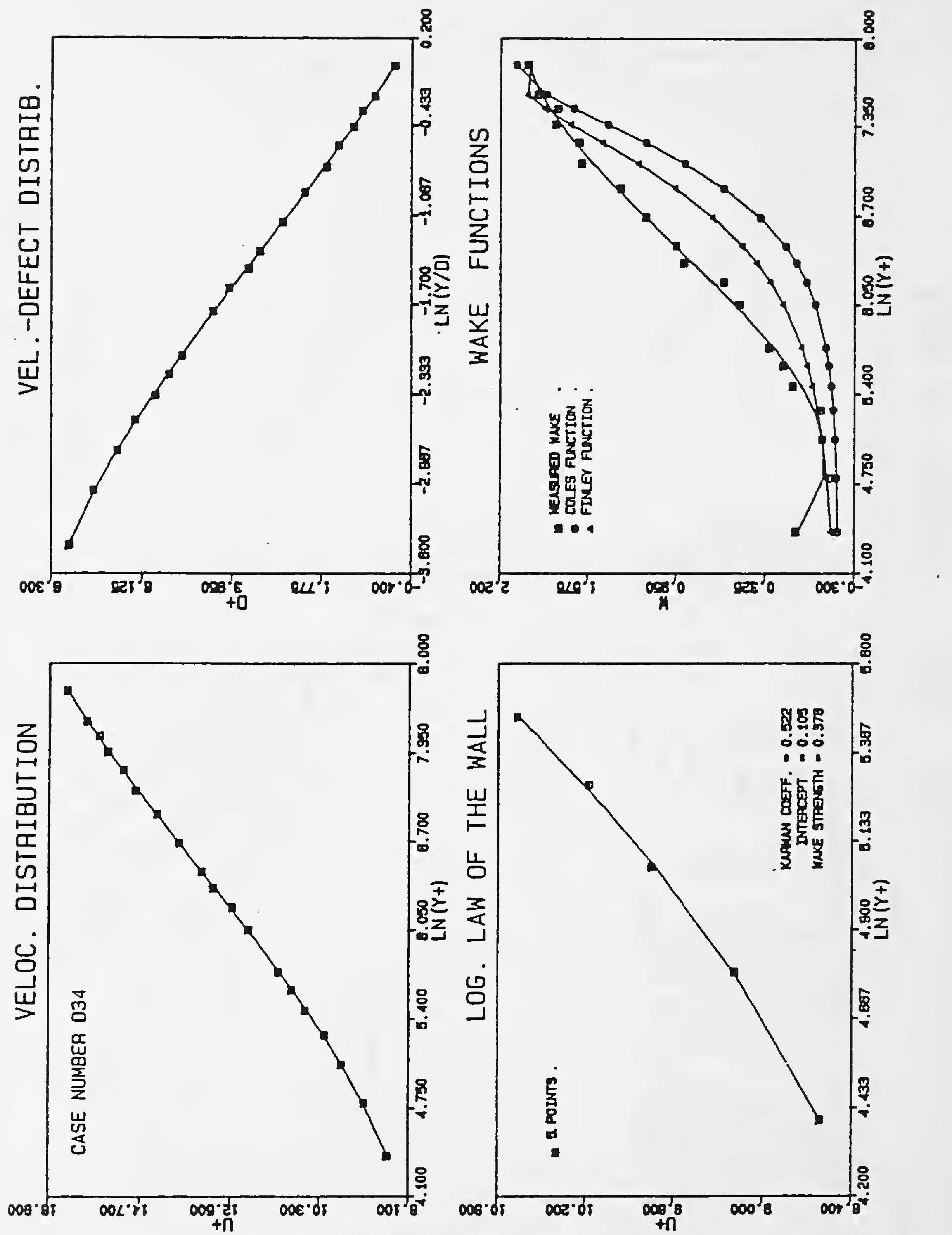


Figure 3.20: Distributions assuming null virtual origin. Case number 34.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

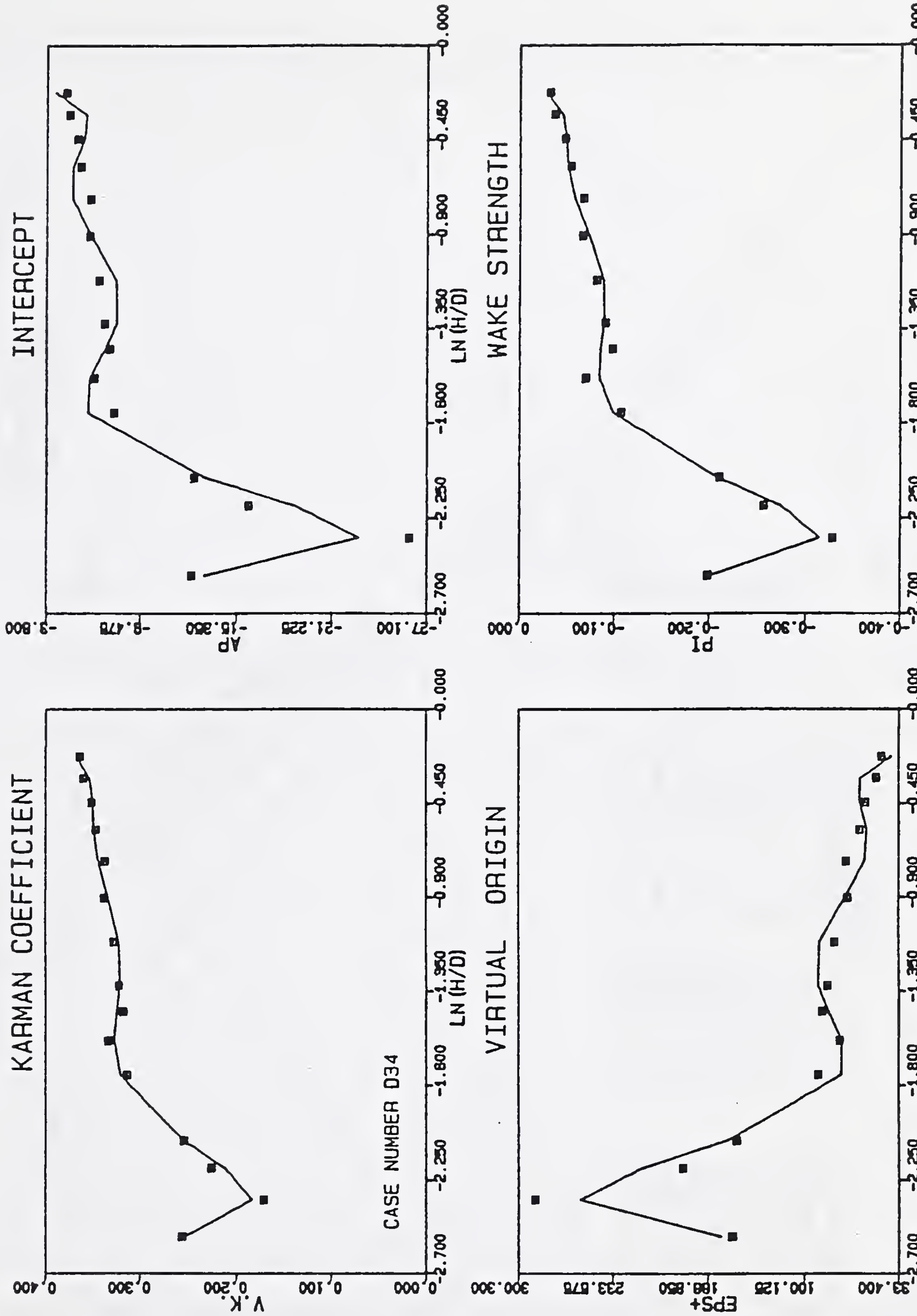


Figure 3.21: Parameter variation with the virtual-origin-search thickness H. Case number 34. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

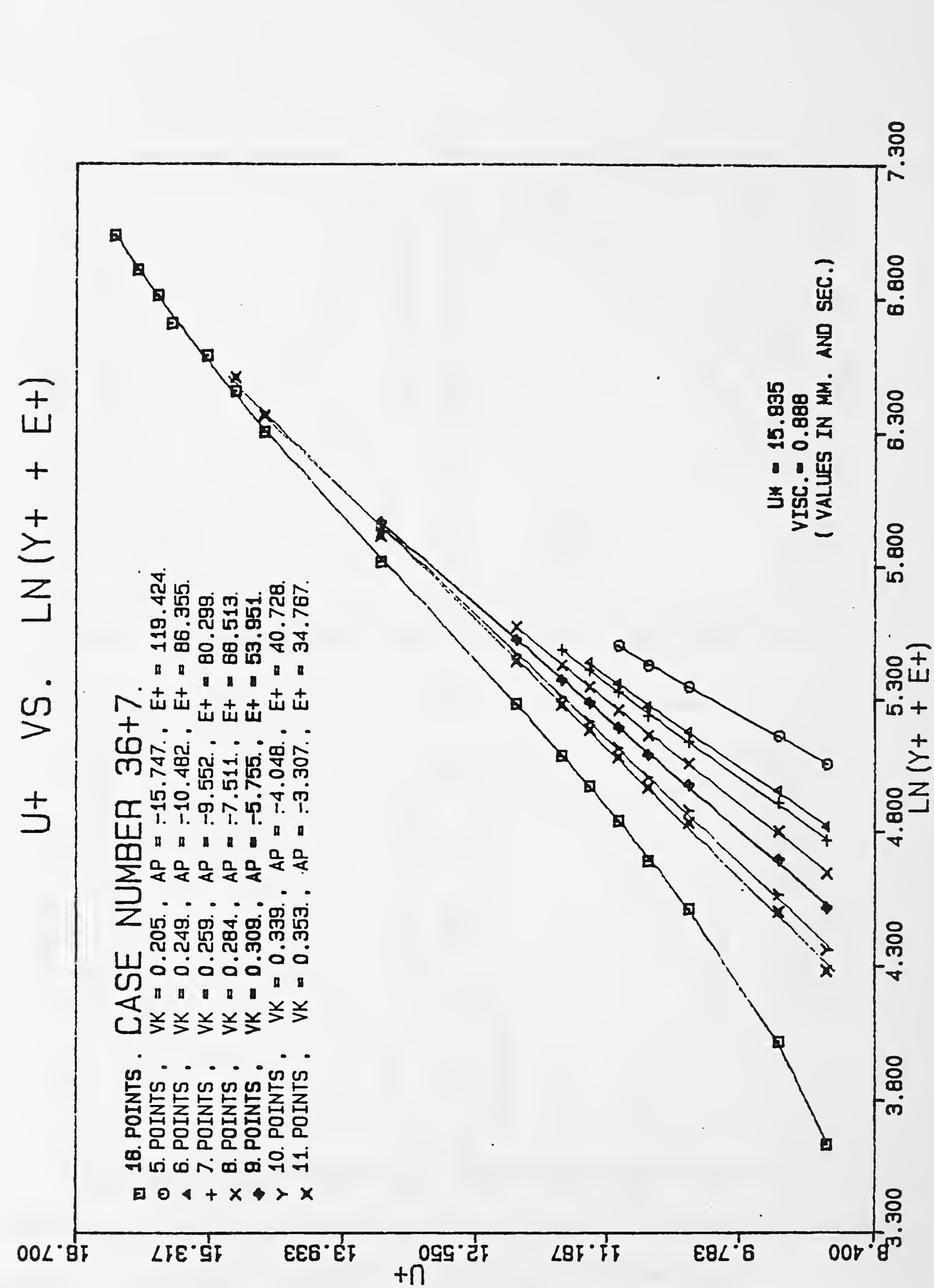


Figure 3.22 : Virtual-origin search. Case number 36+7.

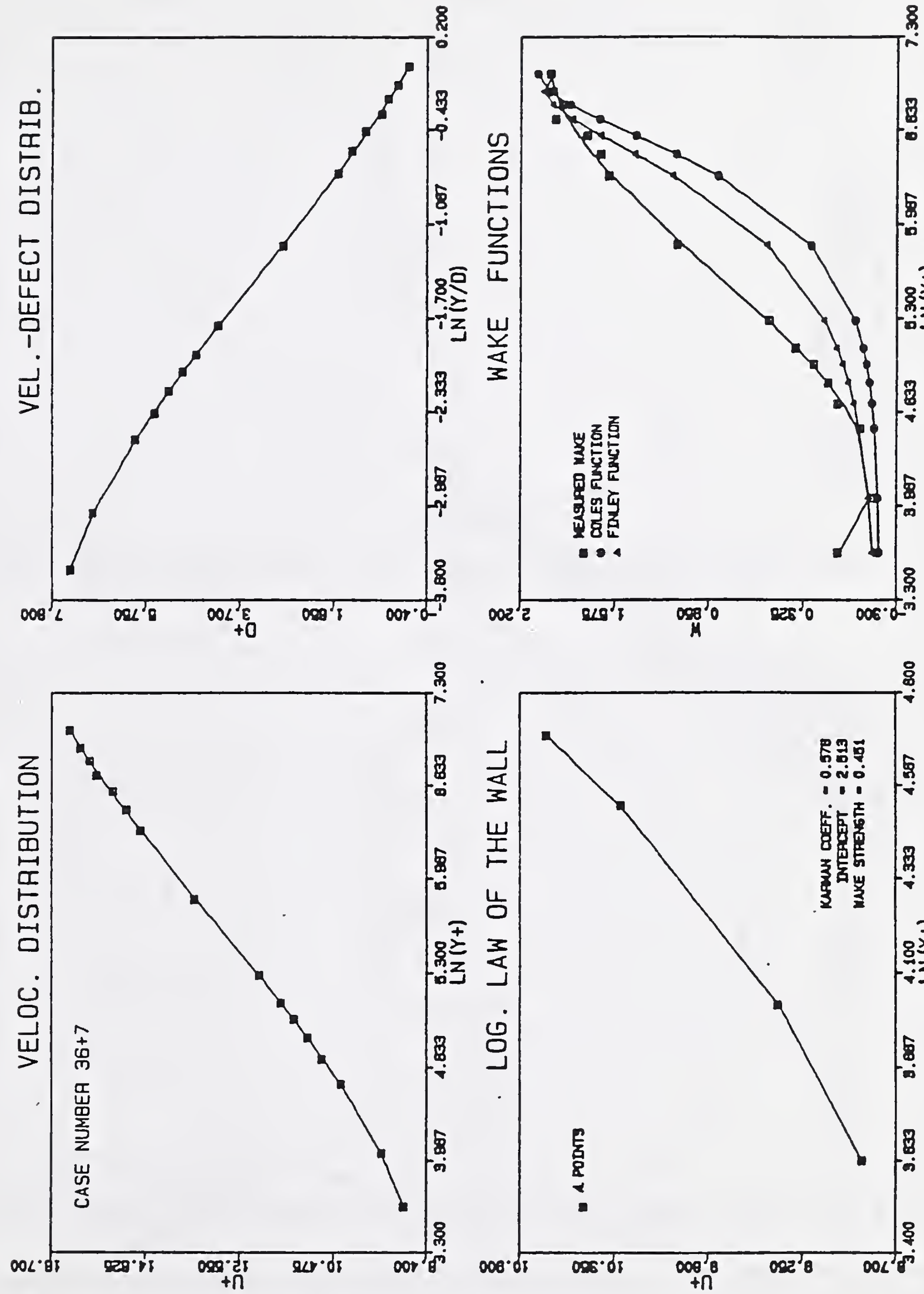


Figure 3.23: Distributions assuming null virtual origin. Case number 36.7.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

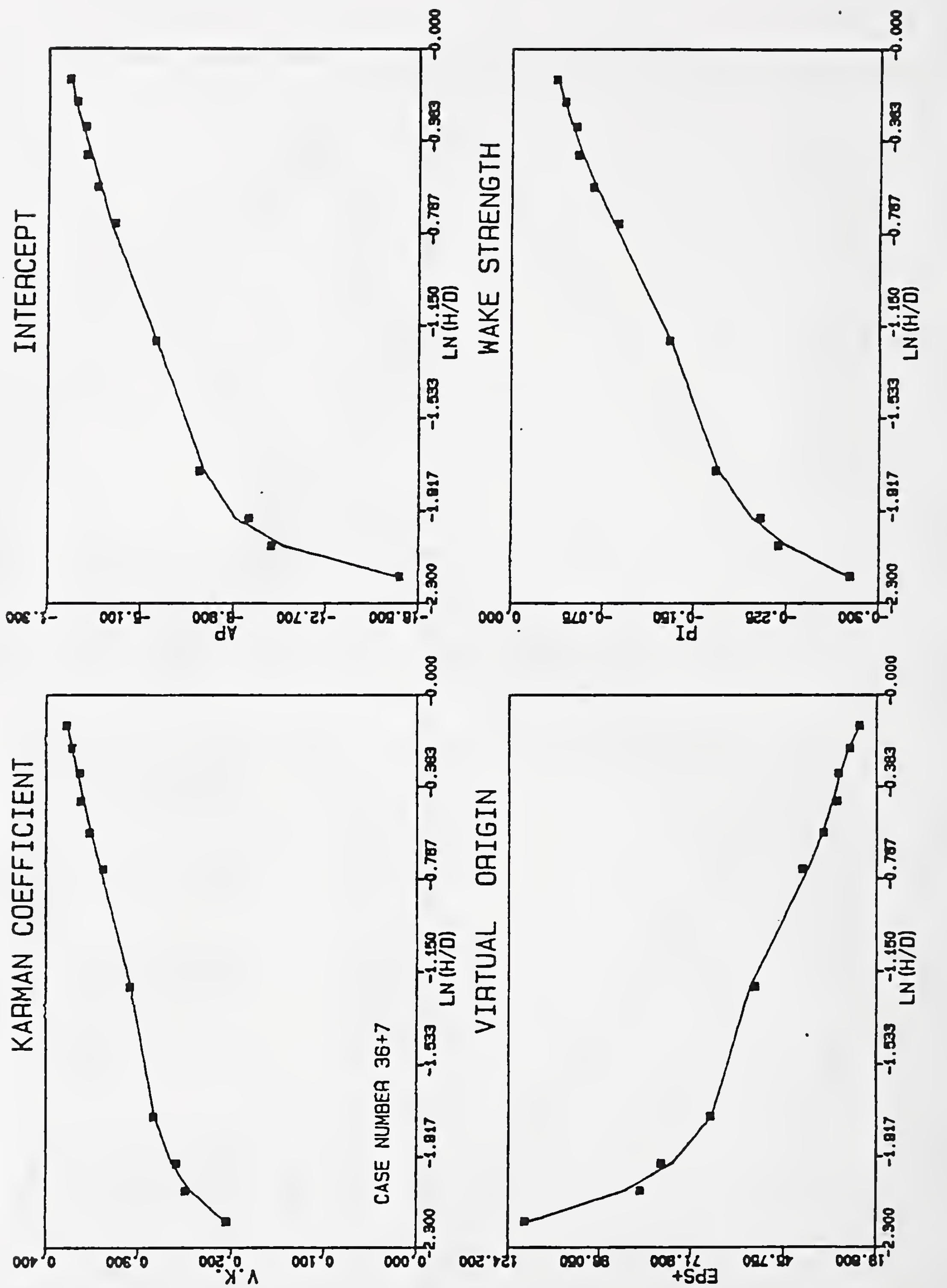


Figure 3.24: Parameter variation with the virtual-origin-search thickness H. Case number 36+7. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

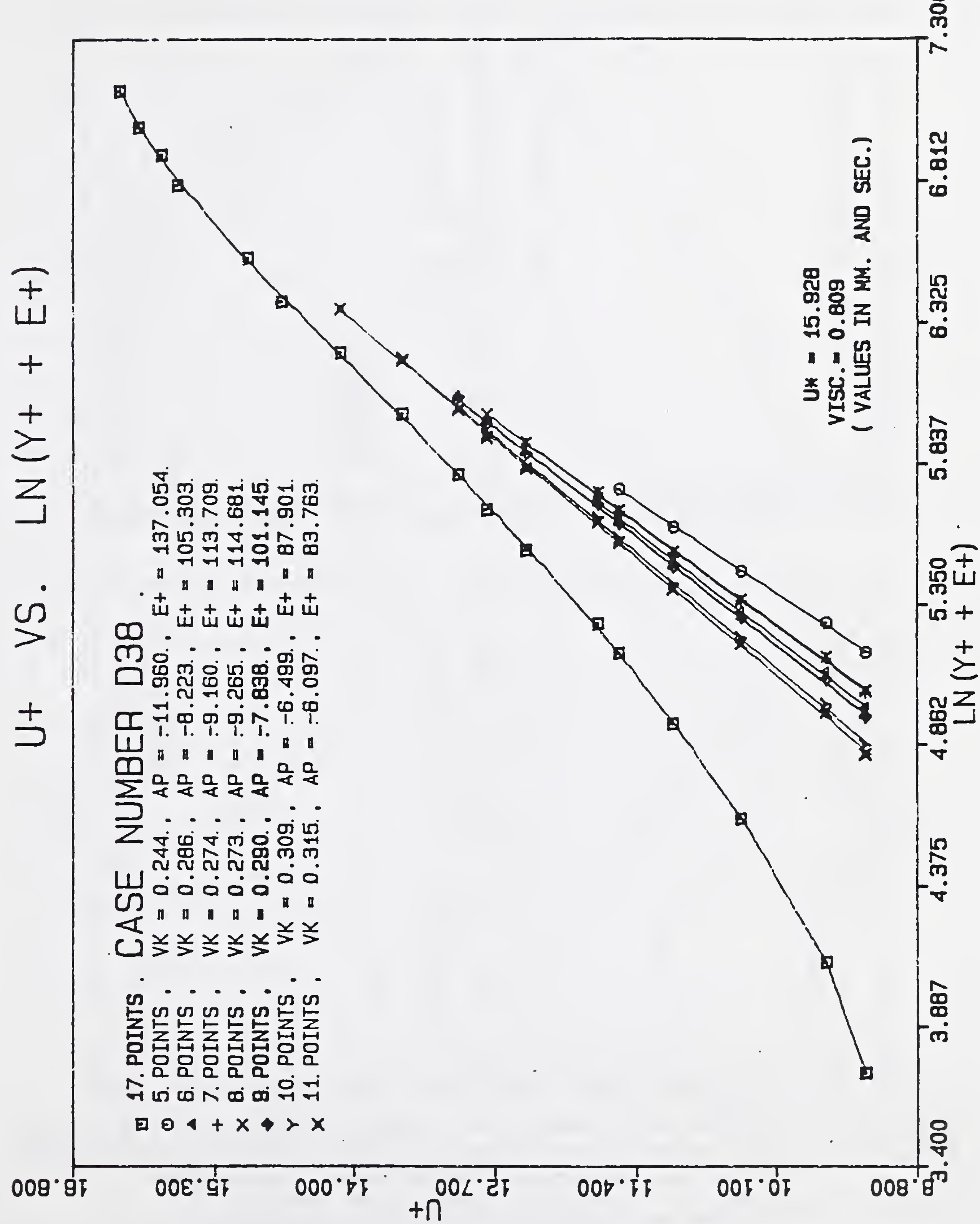


Figure 3.25 : Virtual-origin search. Case number 38.

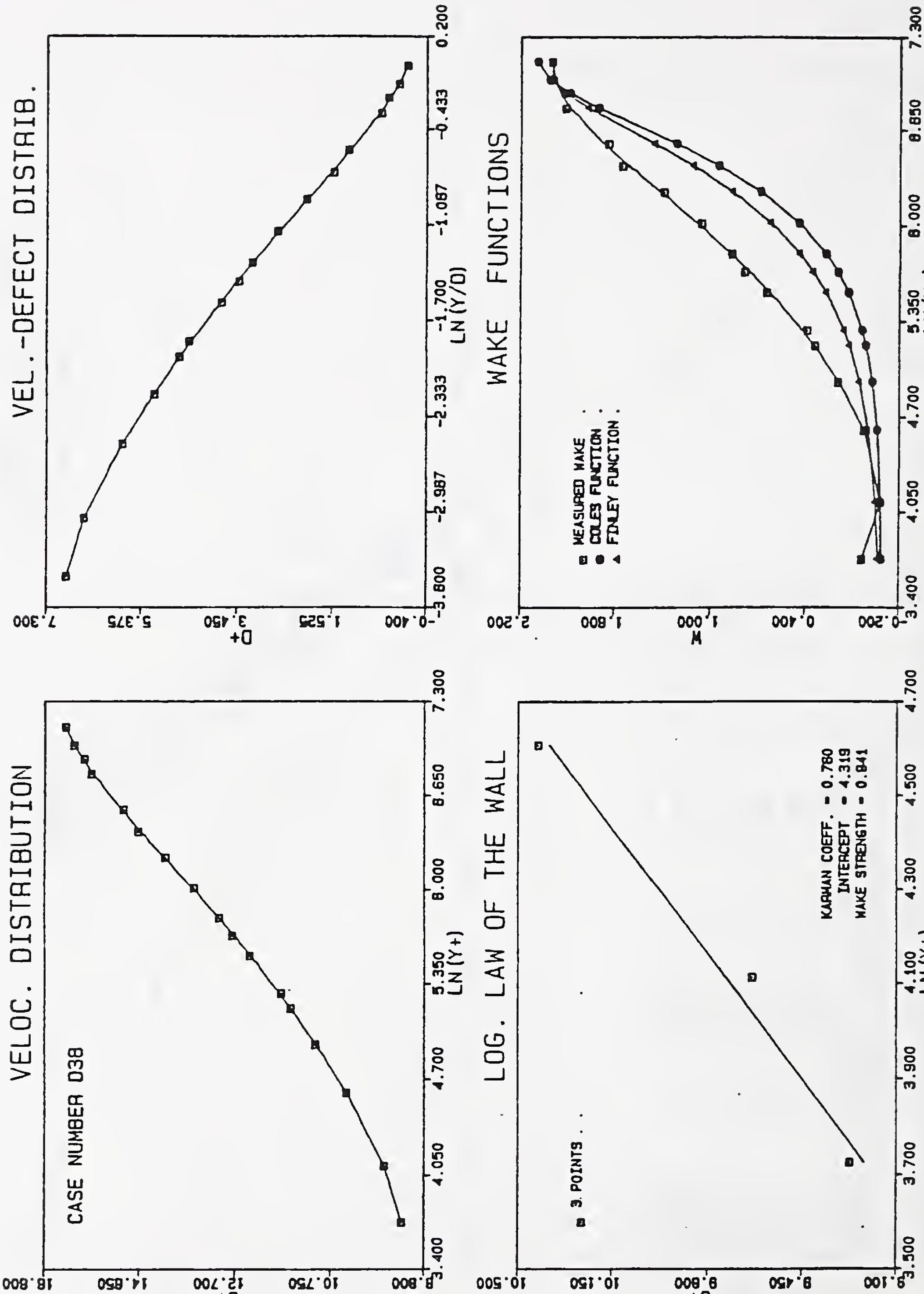


Figure 3.26: Distributions assuming null virtual origin. Case number 38.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

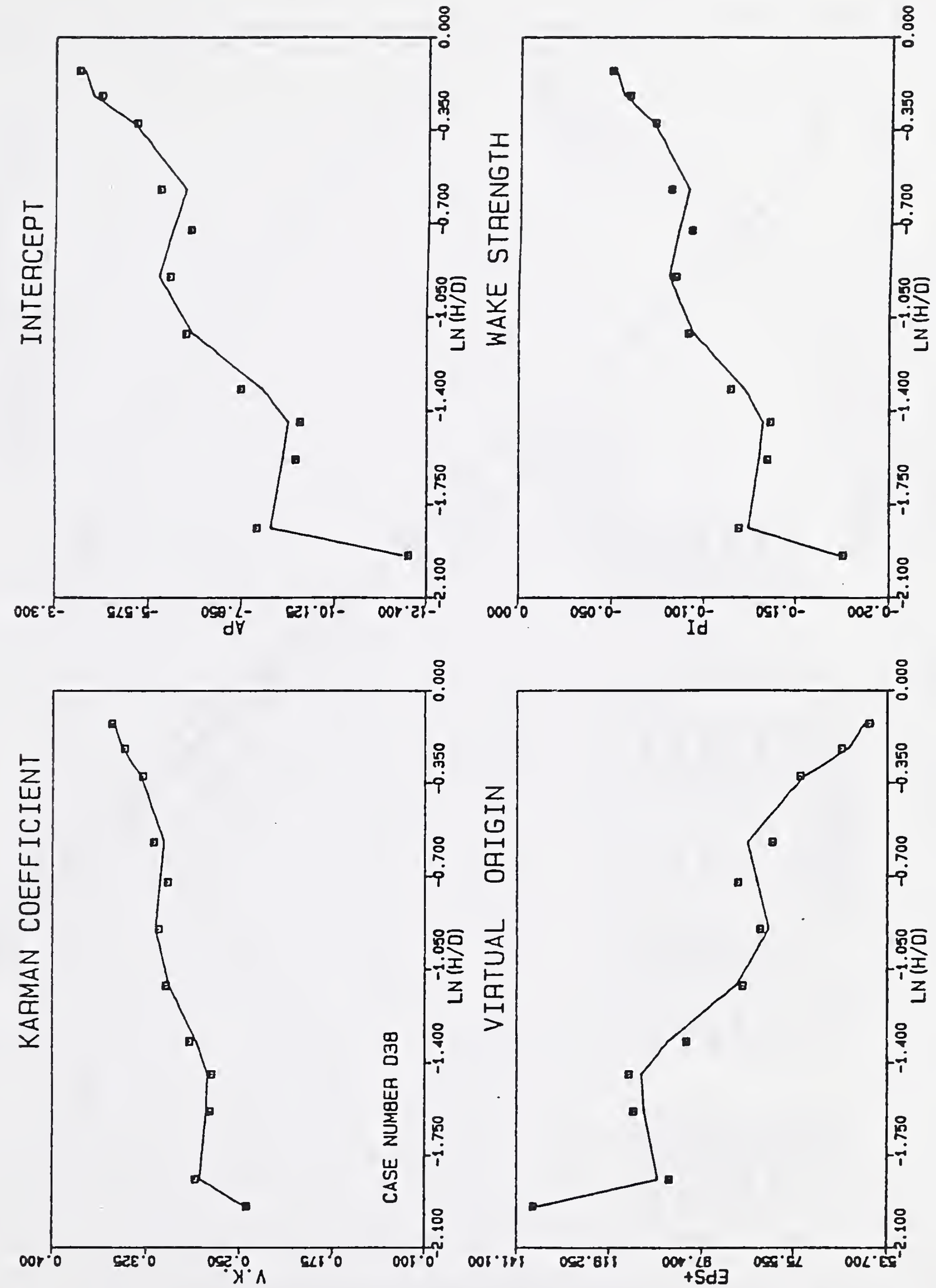


Figure 3.27: Parameter variation with the virtual-origin-search thickness H. Case number 38. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

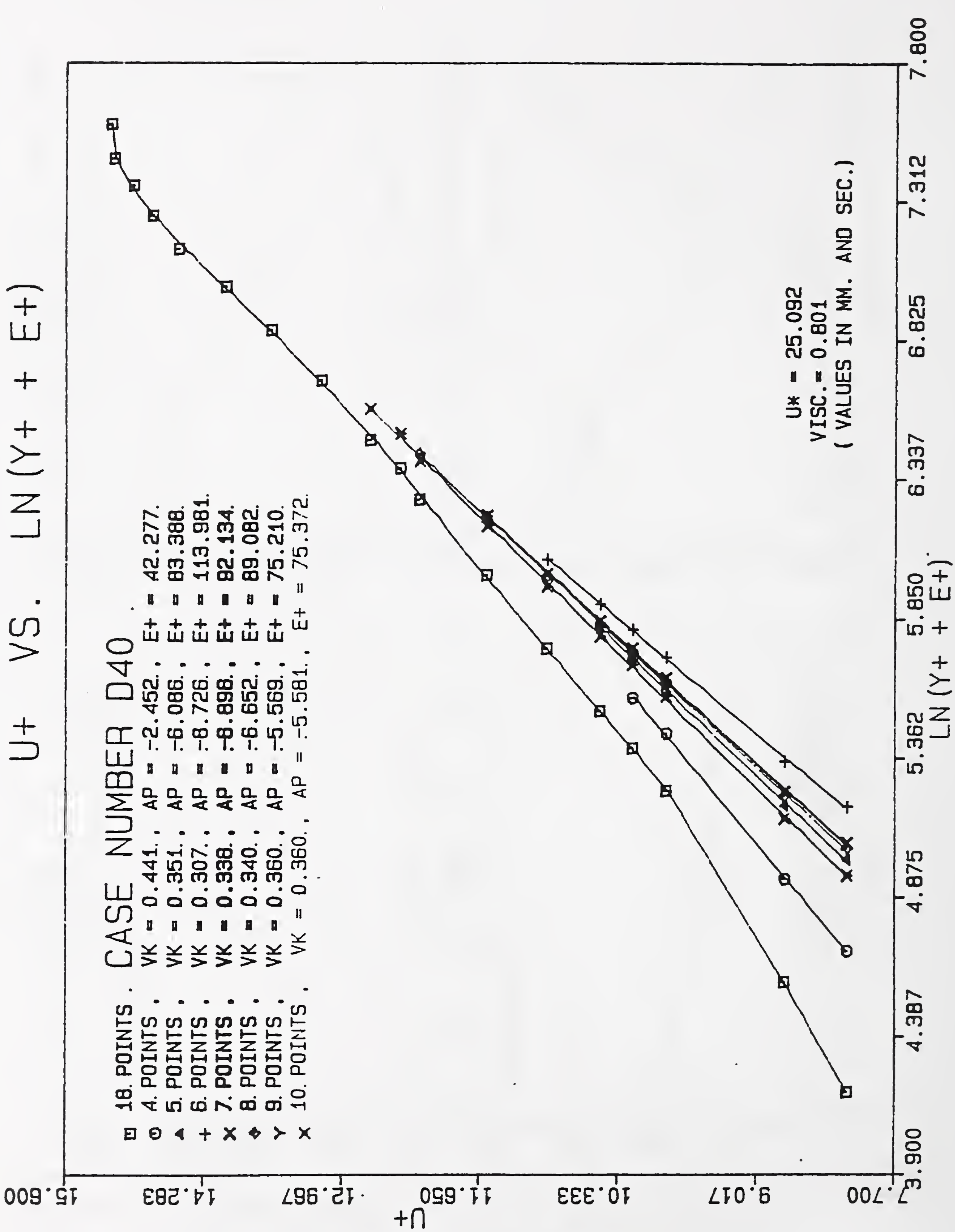


Figure 3.28 : Virtual-origin search. Case number 40.

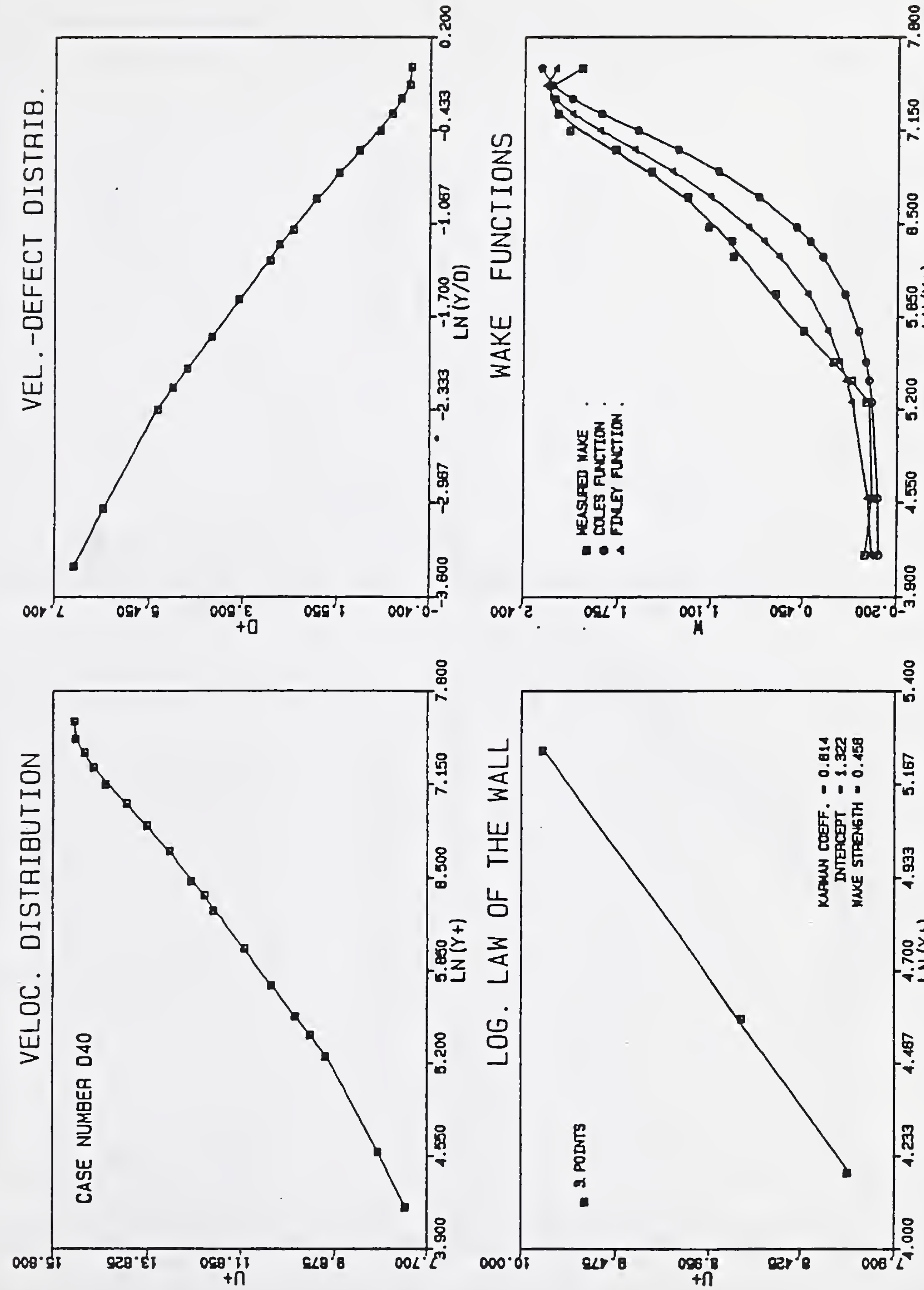


Figure 3.29: Distributions assuming null virtual origin. Case number 40.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

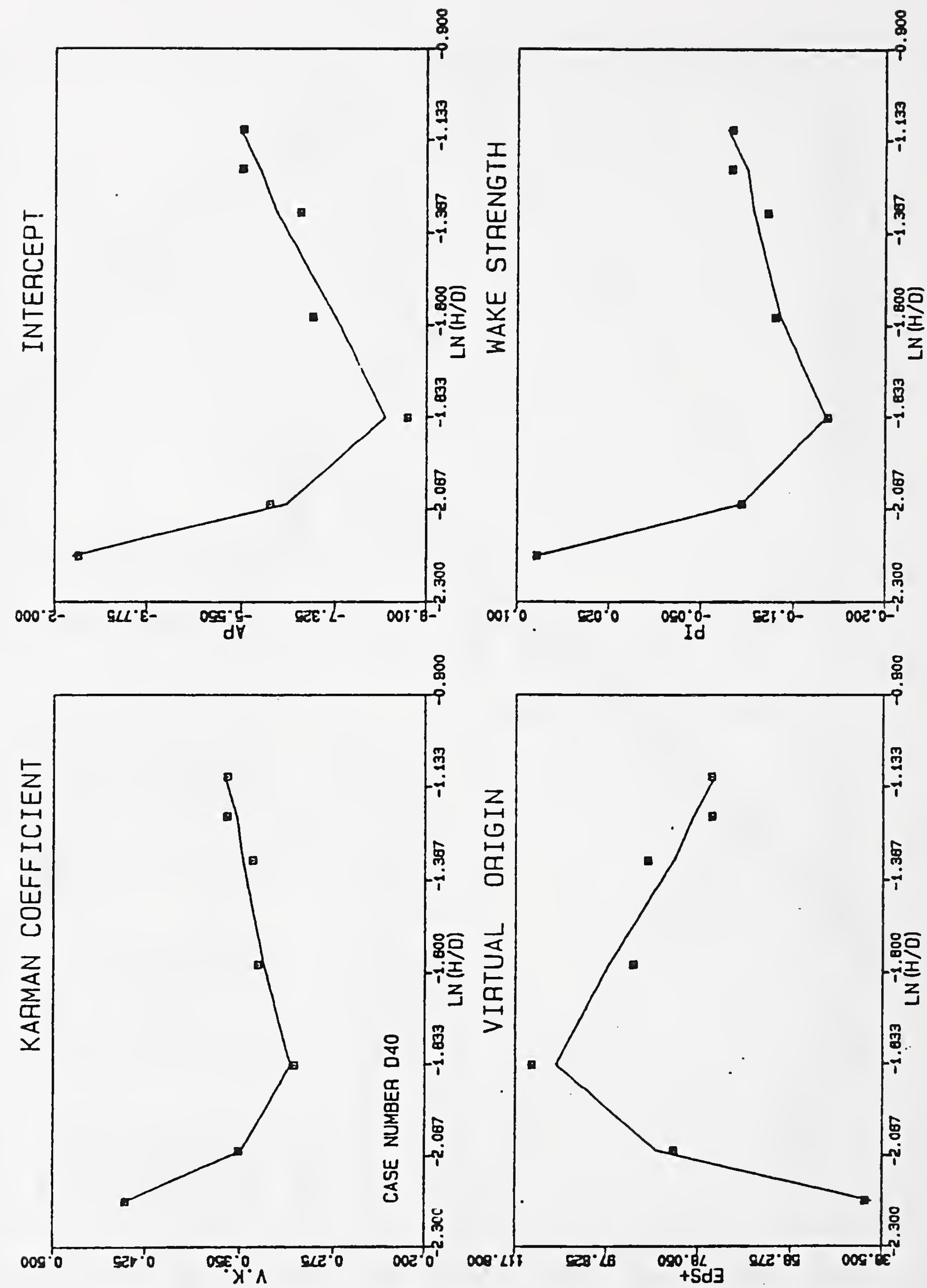


Figure 3.30: Parameter variation with the virtual-origin-search thickness H. Case number 40. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

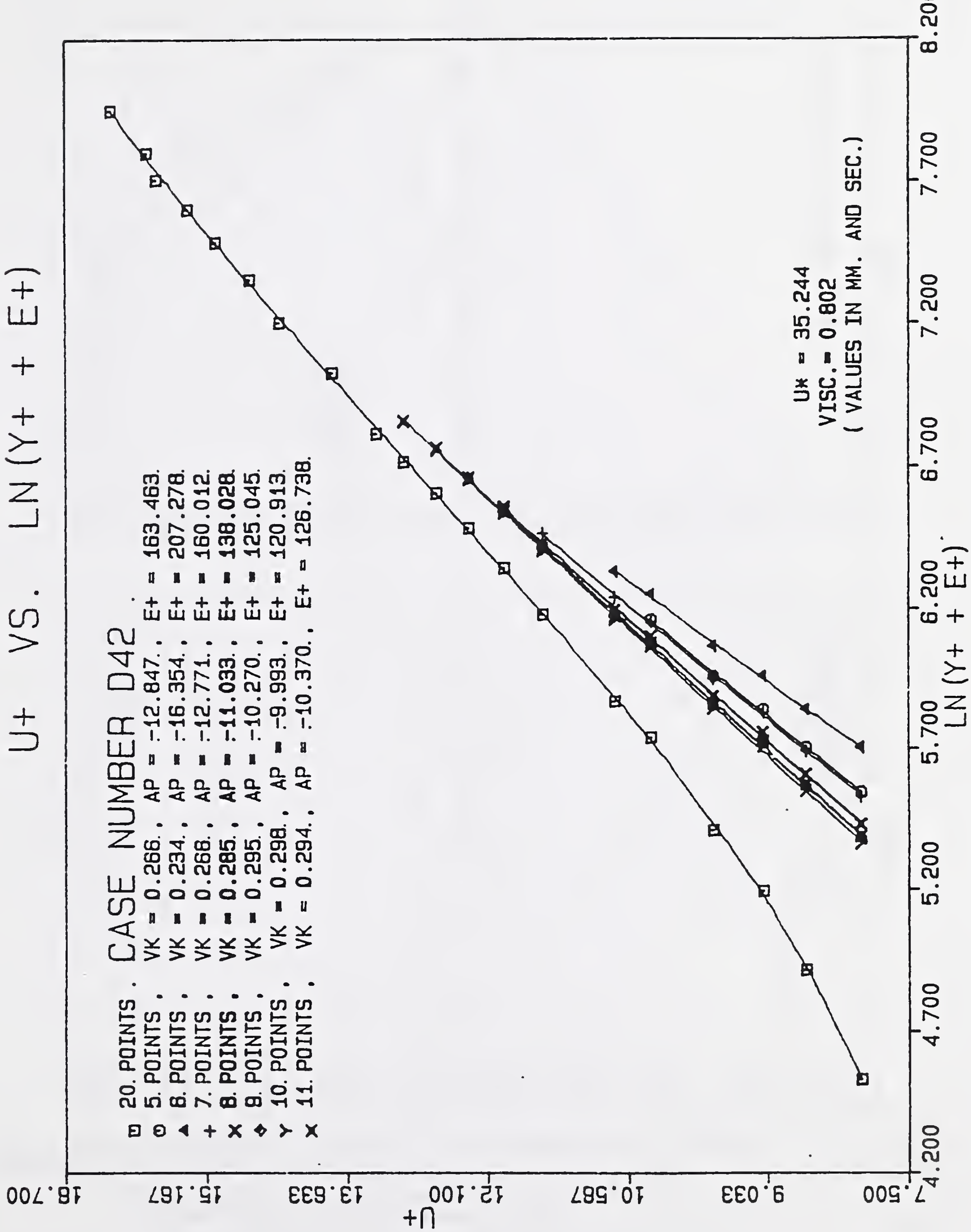


Figure 3.31 : Virtual-origin search. Case number 42.

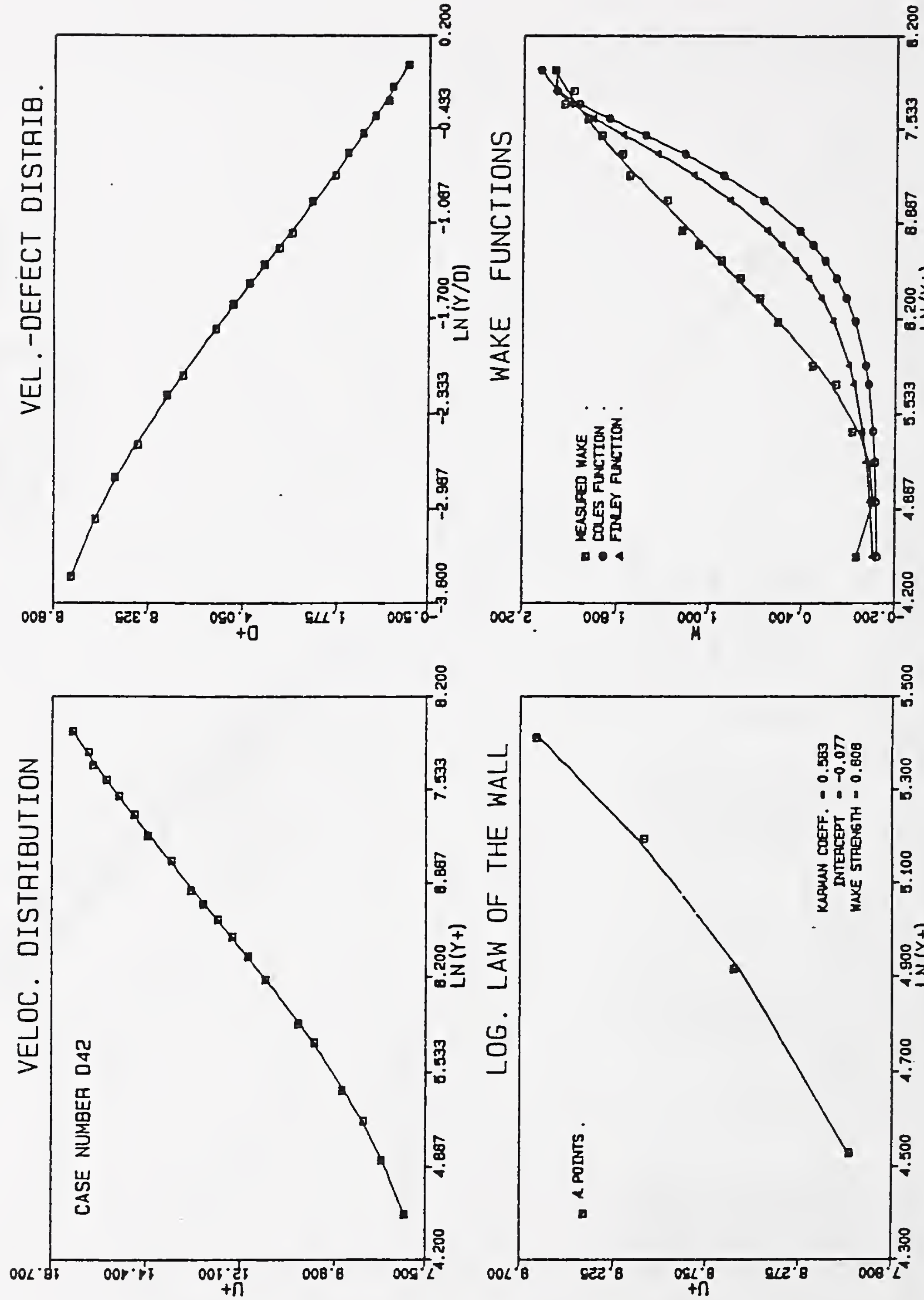


Figure 3.32: Distributions assuming null virtual origin. Case number 42.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

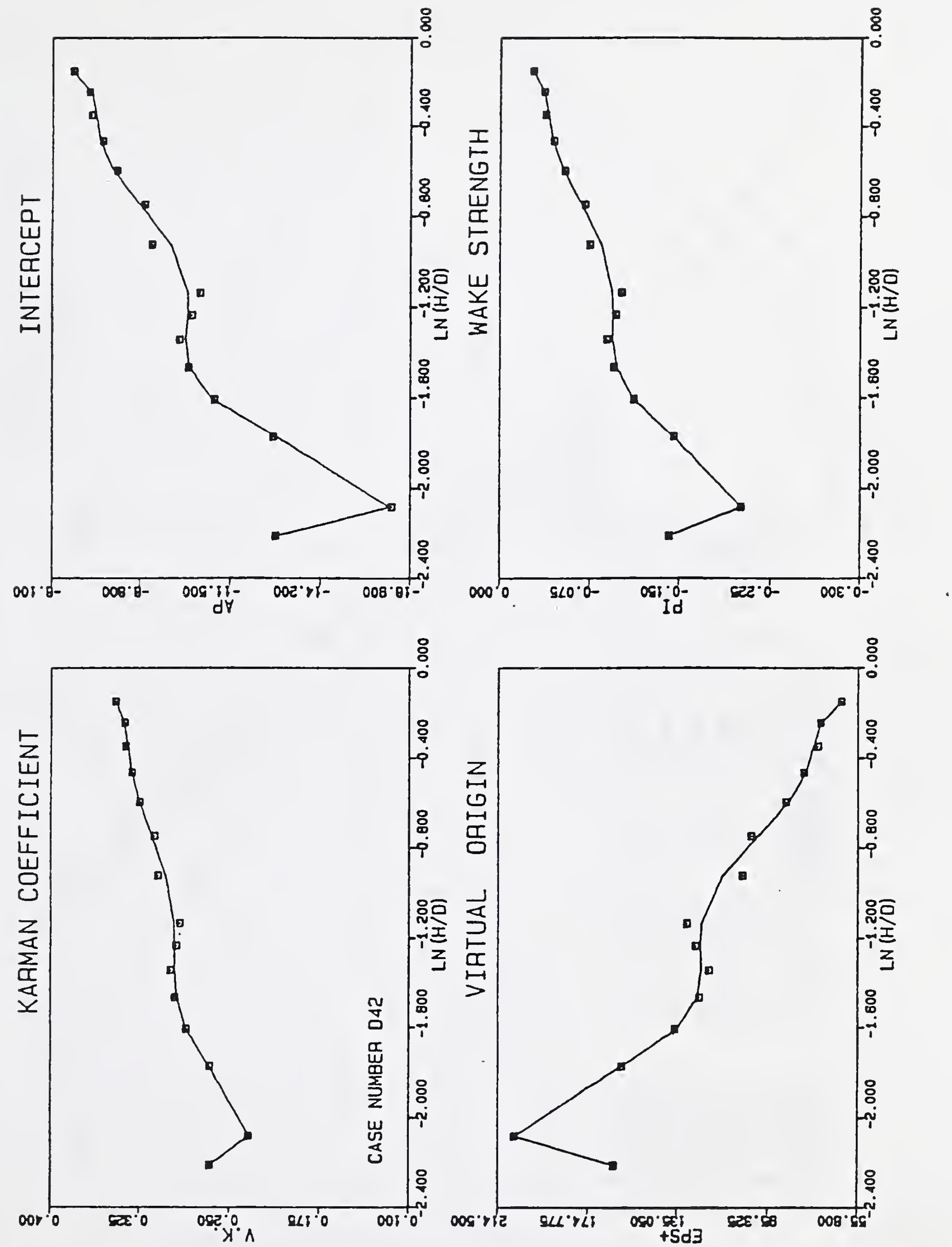


Figure 3.33: Parameter variation with the virtual-origin-search thickness H. Case number 42. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

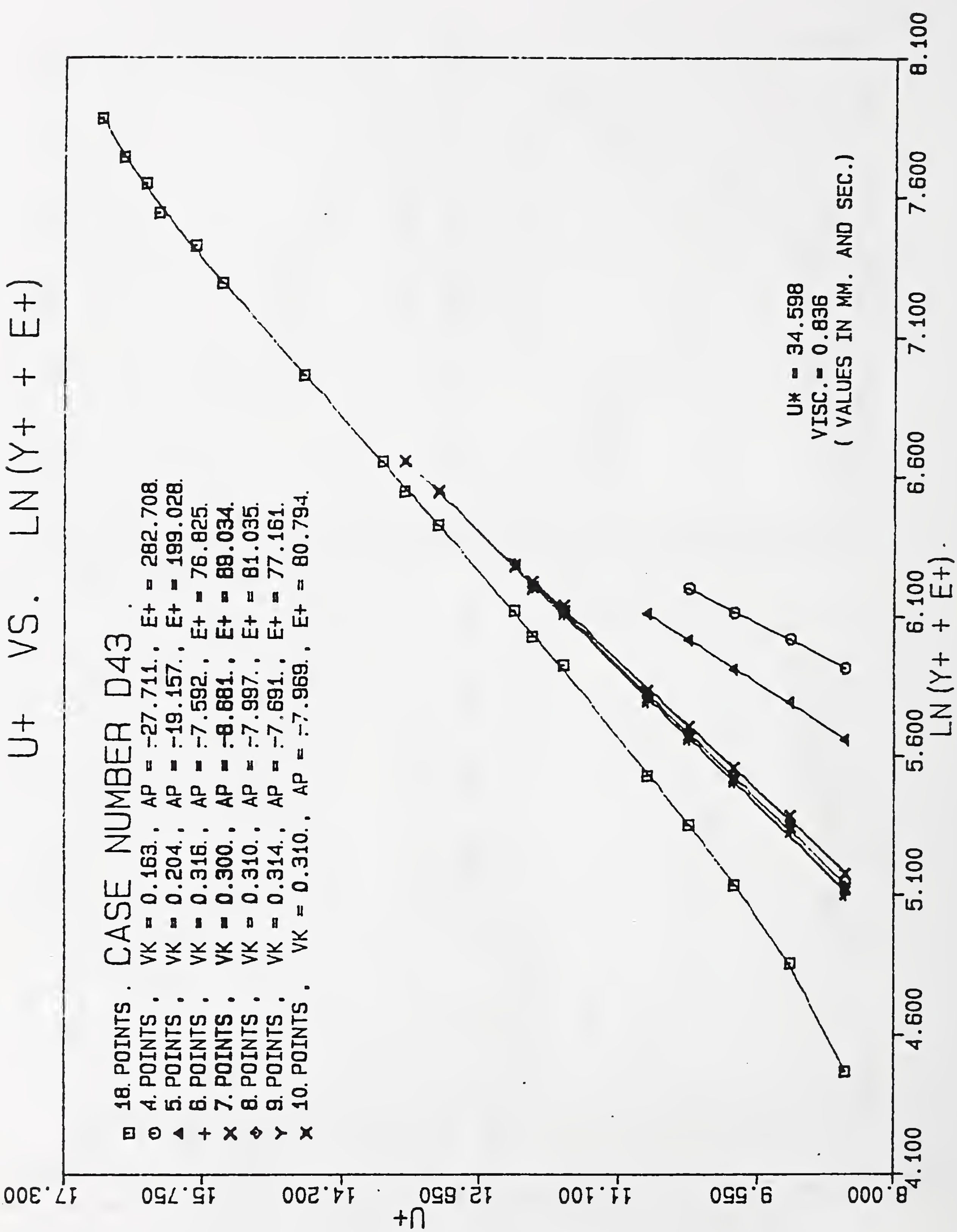


Figure 3.34 : Virtual-origin search. Case number 43.

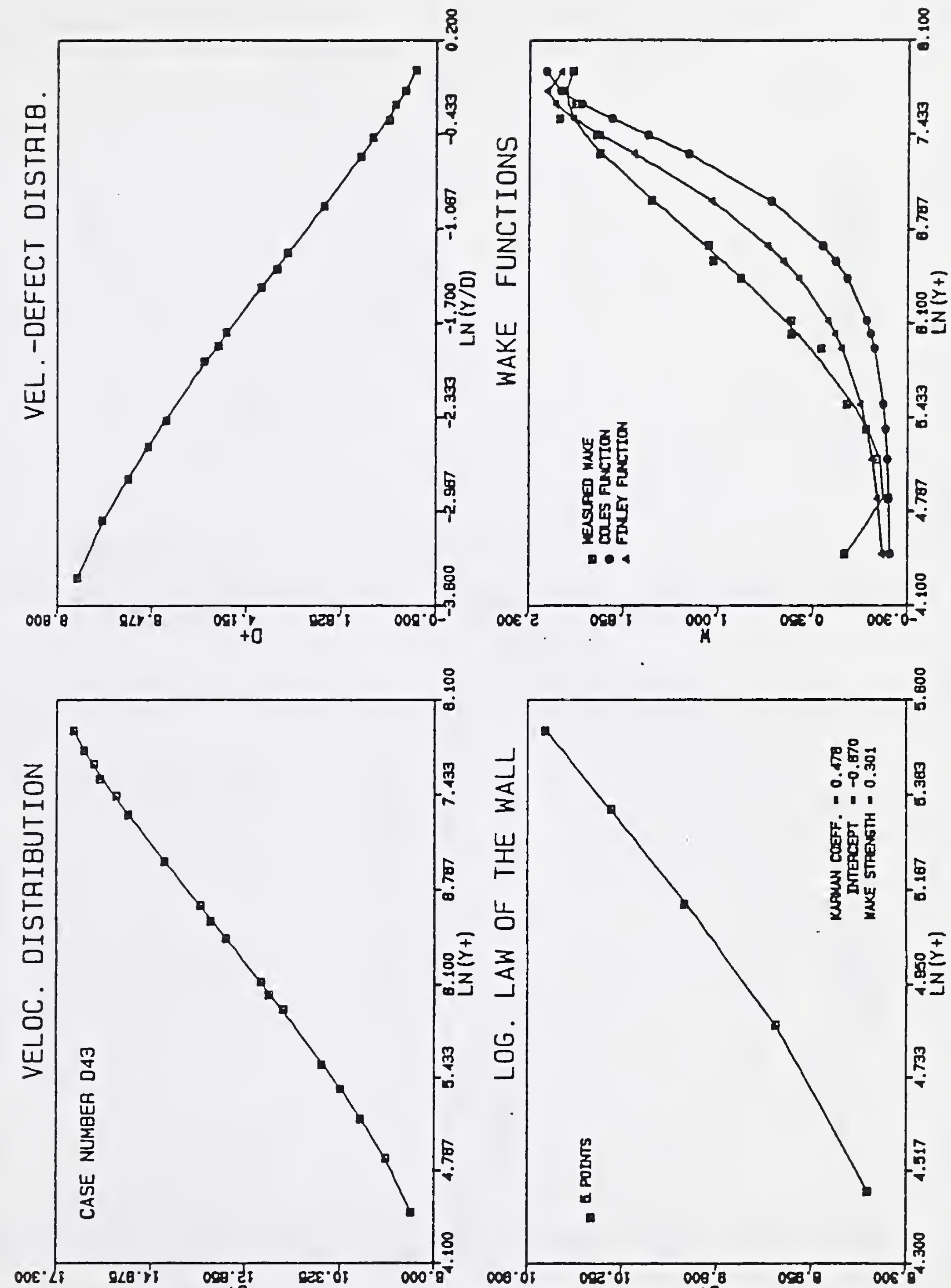


Figure 3.35: Distributions assuming null virtual origin. Case number 43.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

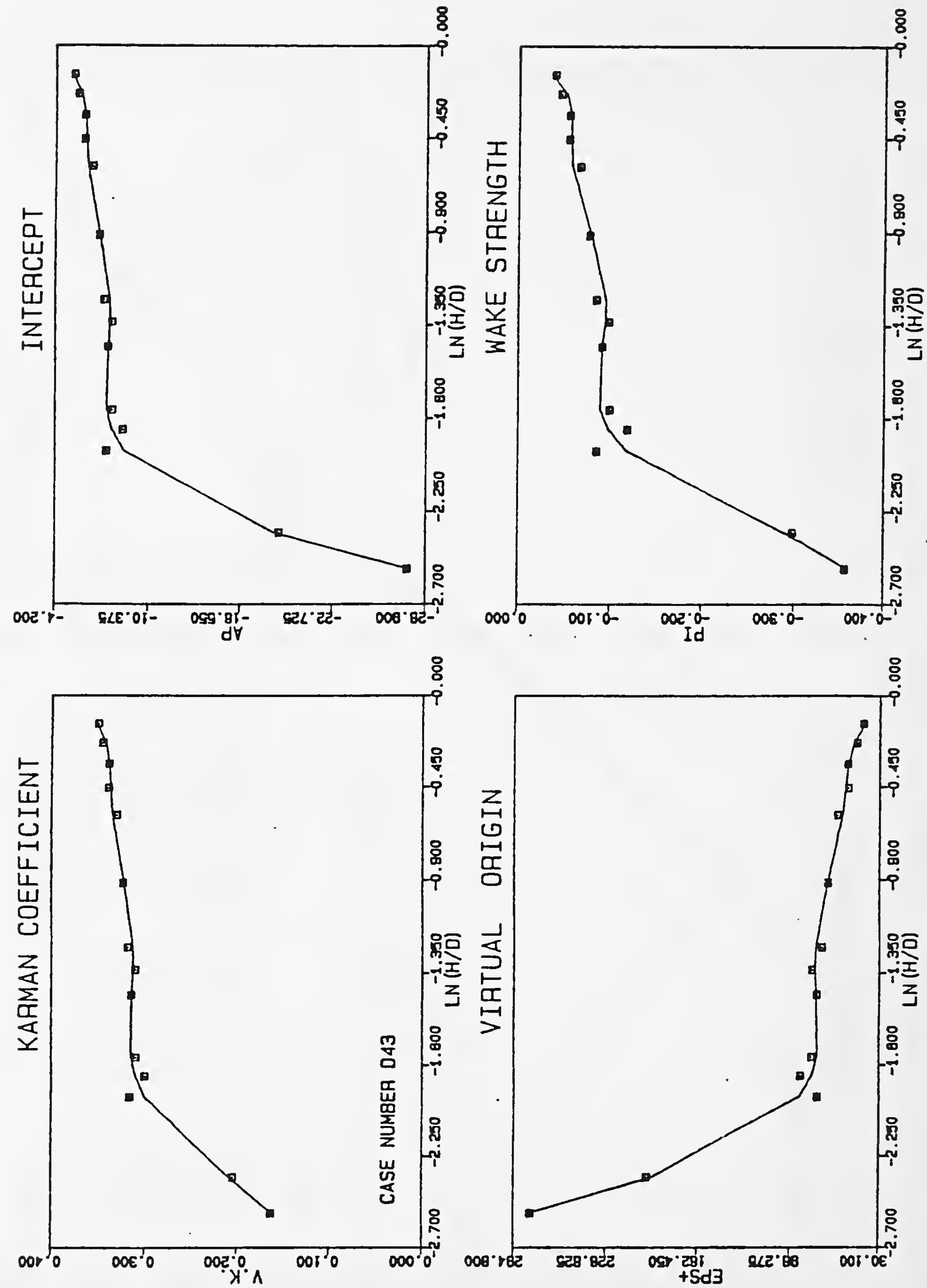


Figure 3.36: Parameter variation with the virtual-origin-search thickness H. Case number 43. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

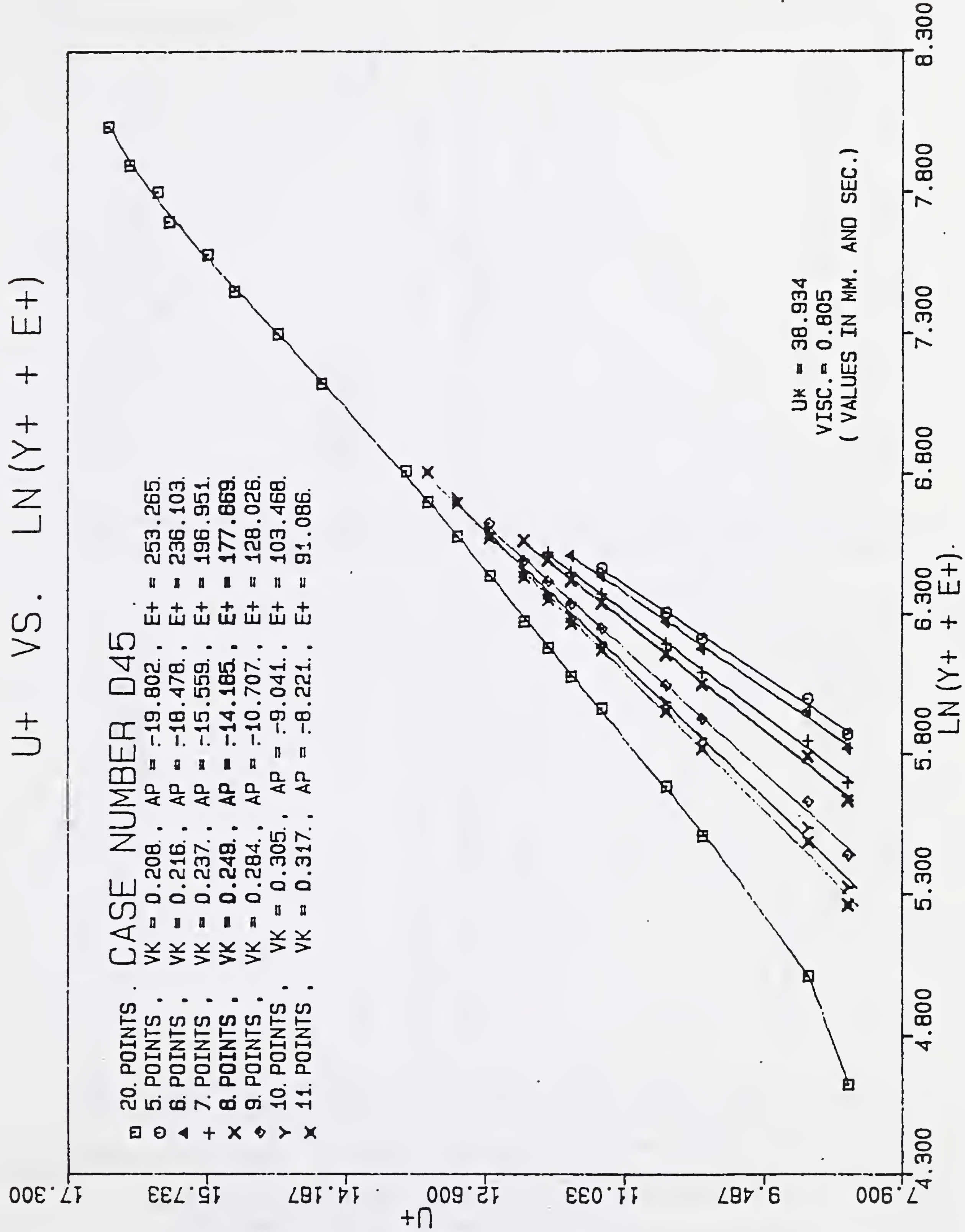


Figure 3.37 : Virtual-origin search. Case number 45.

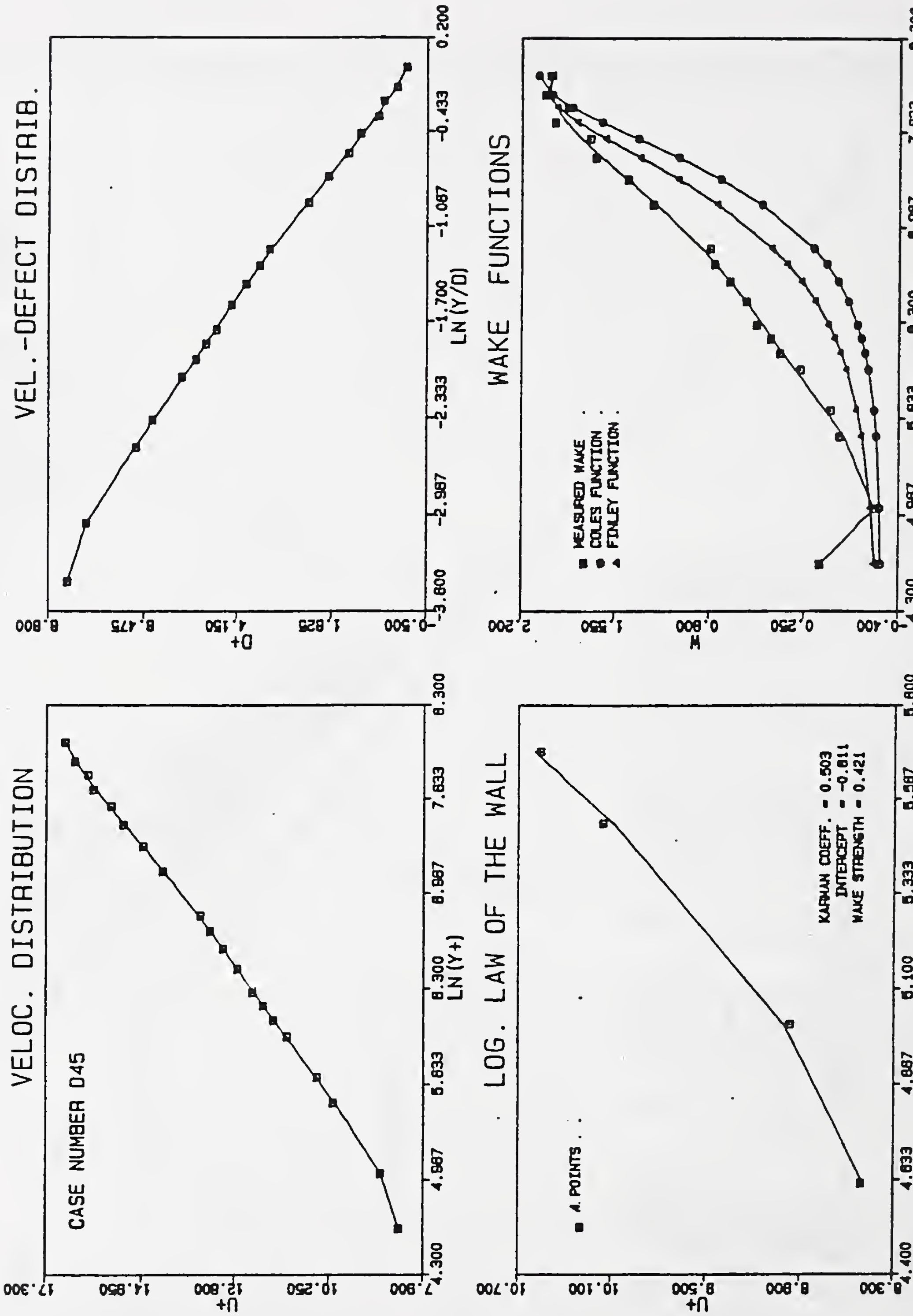


Figure 3.38: Distributions assuming null virtual origin. Case number 45.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

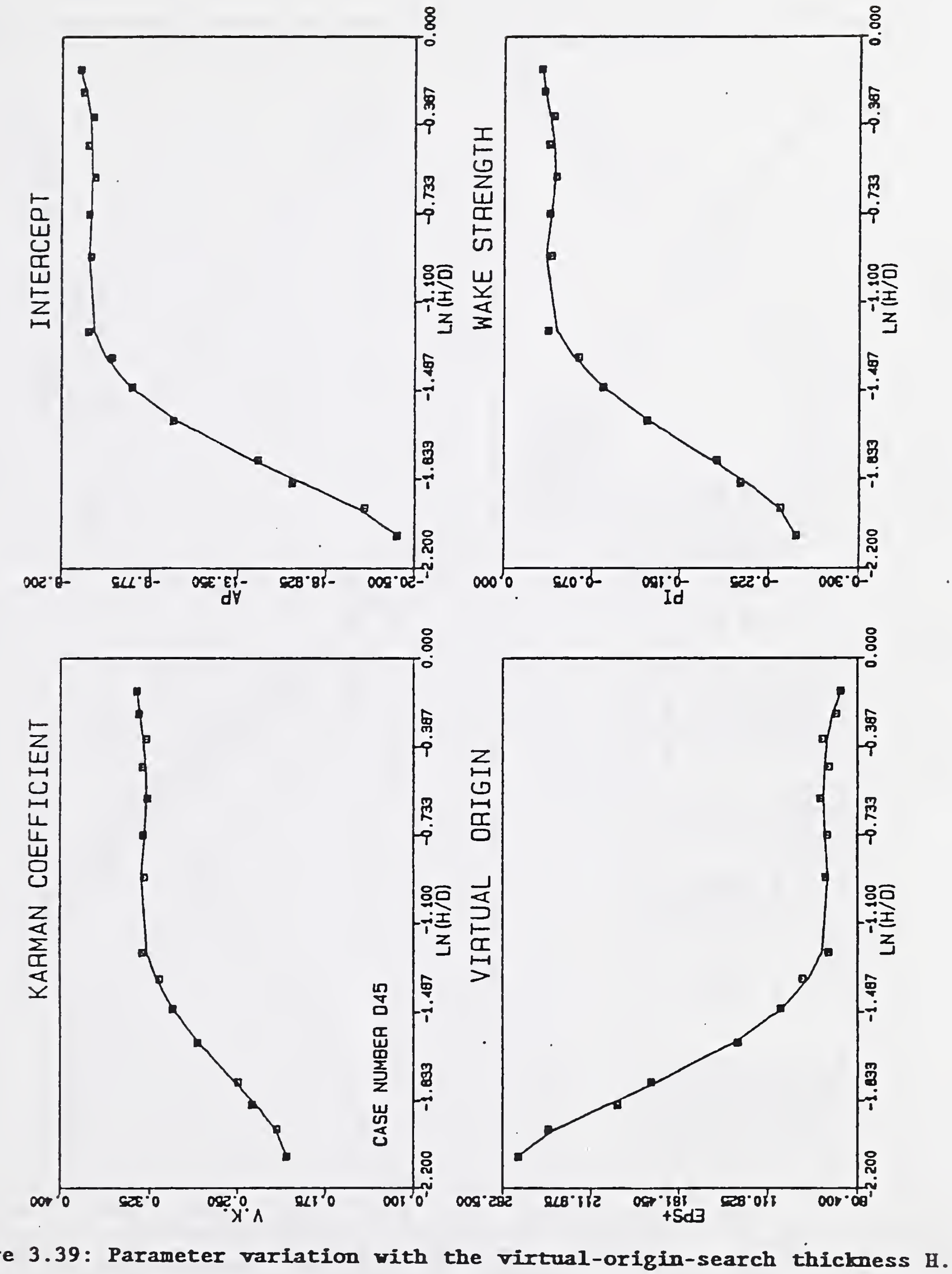


Figure 3.39: Parameter variation with the virtual-origin-search thickness H. Case number 45. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

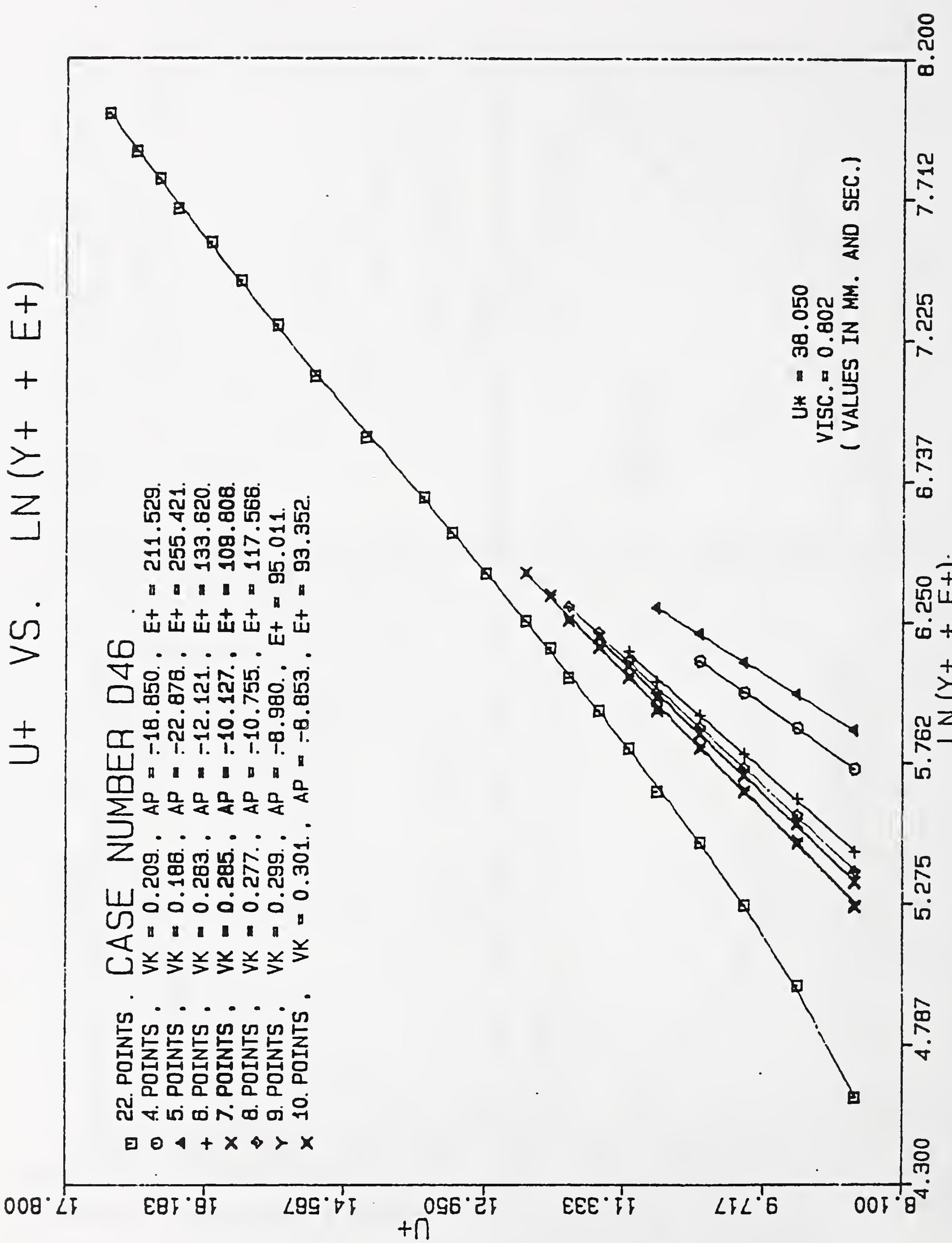


Figure 3.40 : Virtual-origin search. Case number 46.

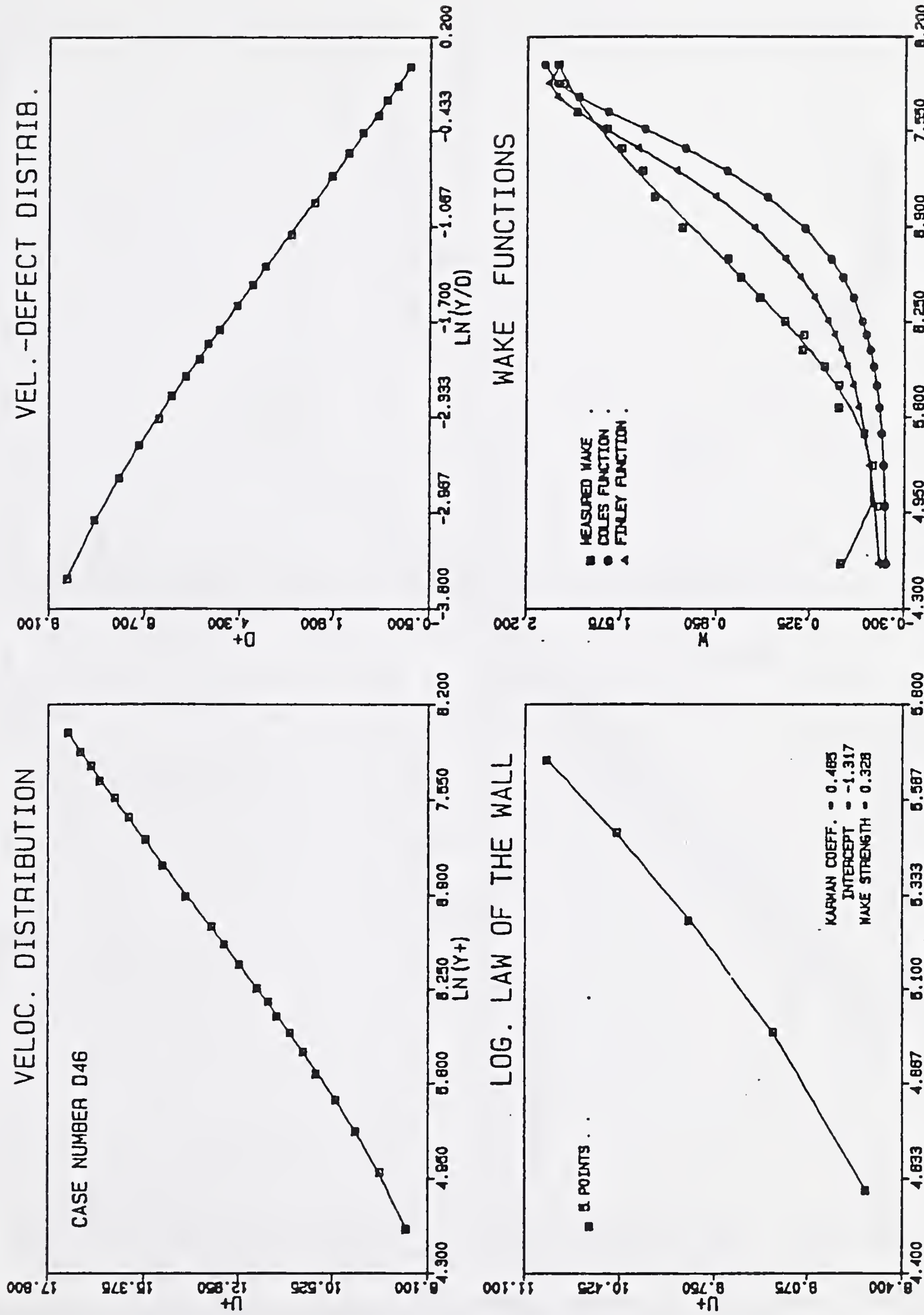


Figure 3.41: Distributions assuming null virtual origin. Case number 46.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

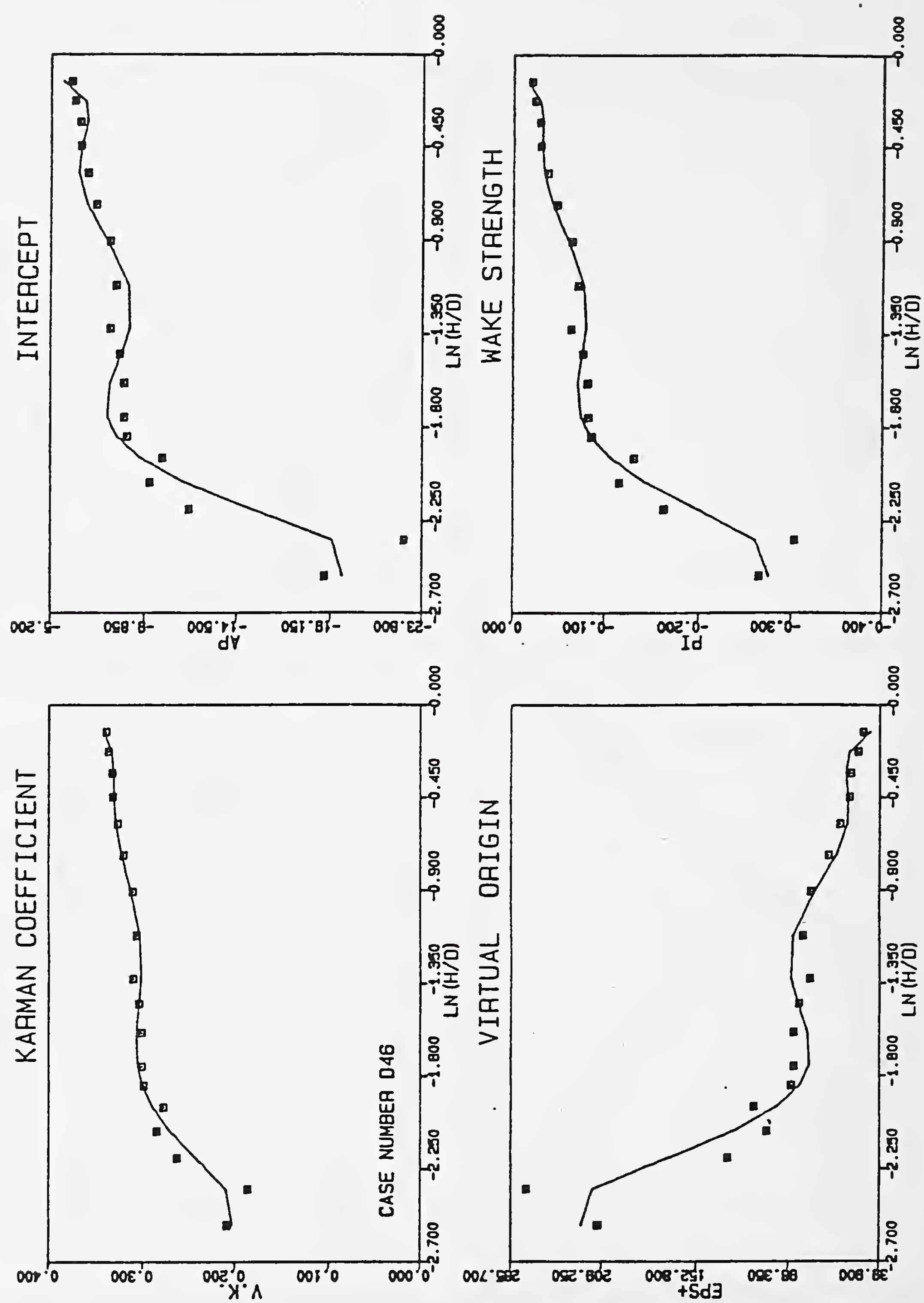


Figure 3.42: Parameter variation with the virtual-origin-search thickness H. Case number 46. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

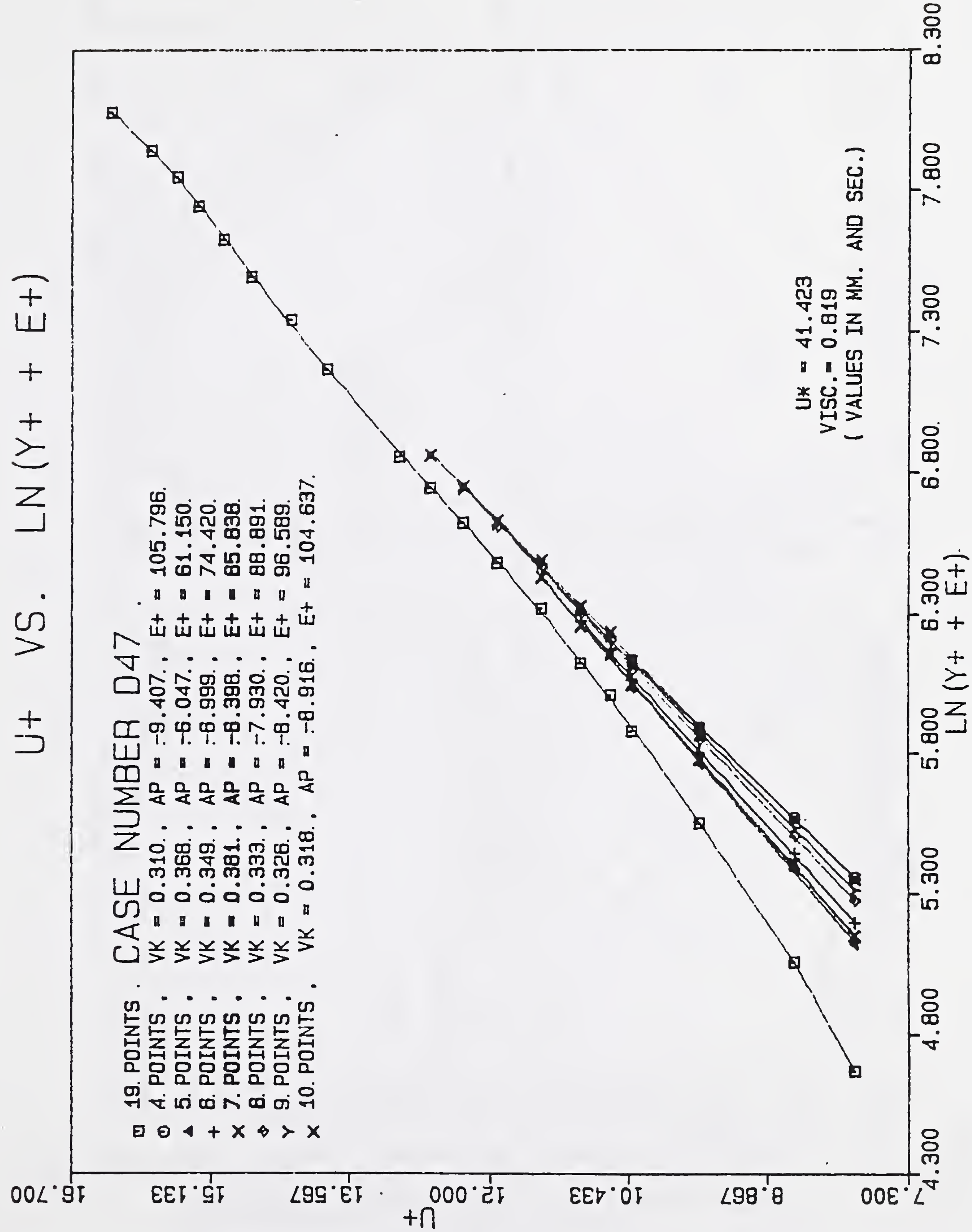


Figure 3.43 : Virtual-origin search. Case number 47.

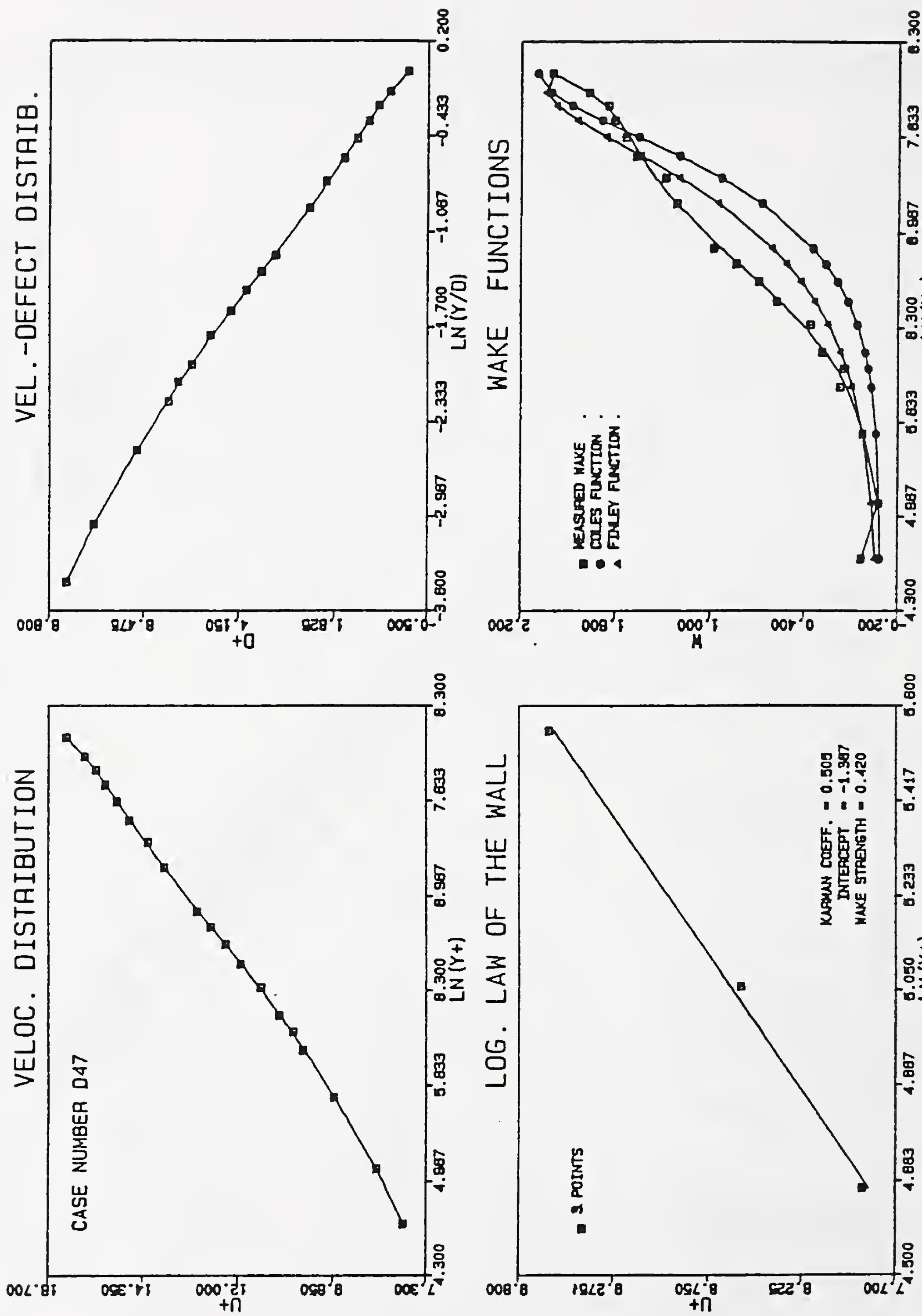


Figure 3.44: Distributions assuming null virtual origin. Case number 47.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

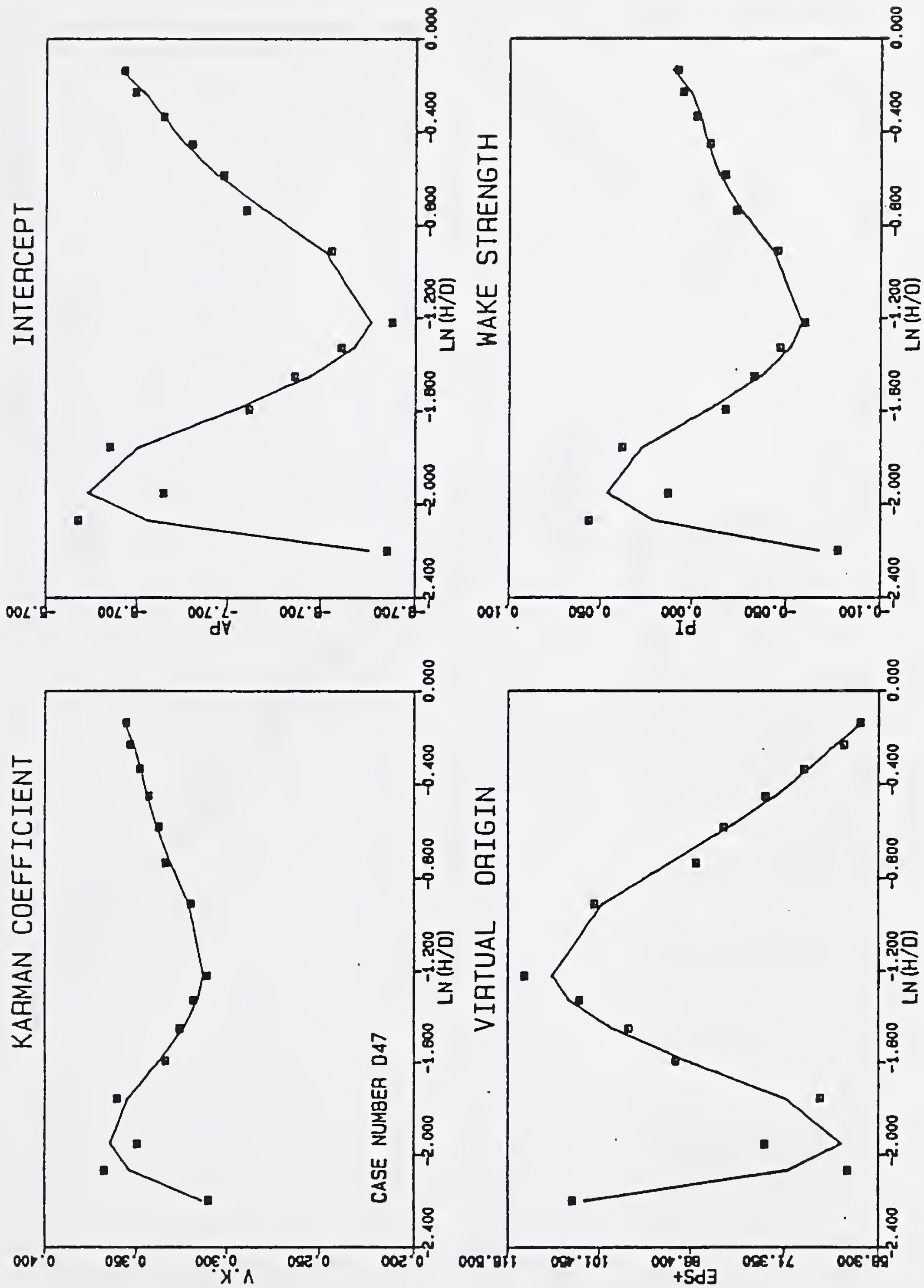


Figure 3.45: Parameter variation with the virtual-origin-search thickness H. Case number 47. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

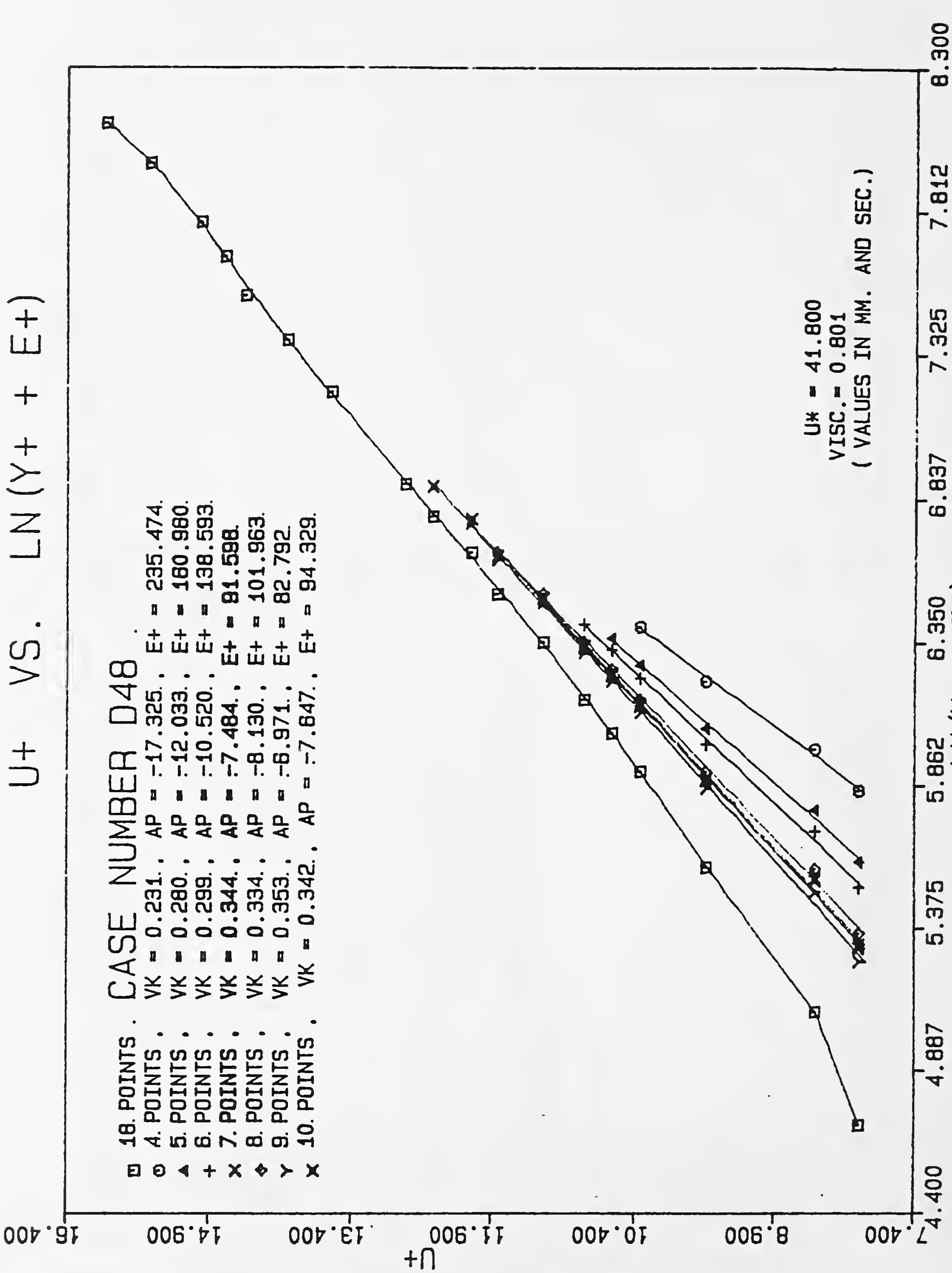


Figure 3.46 : Virtual-origin search. Case number 48.

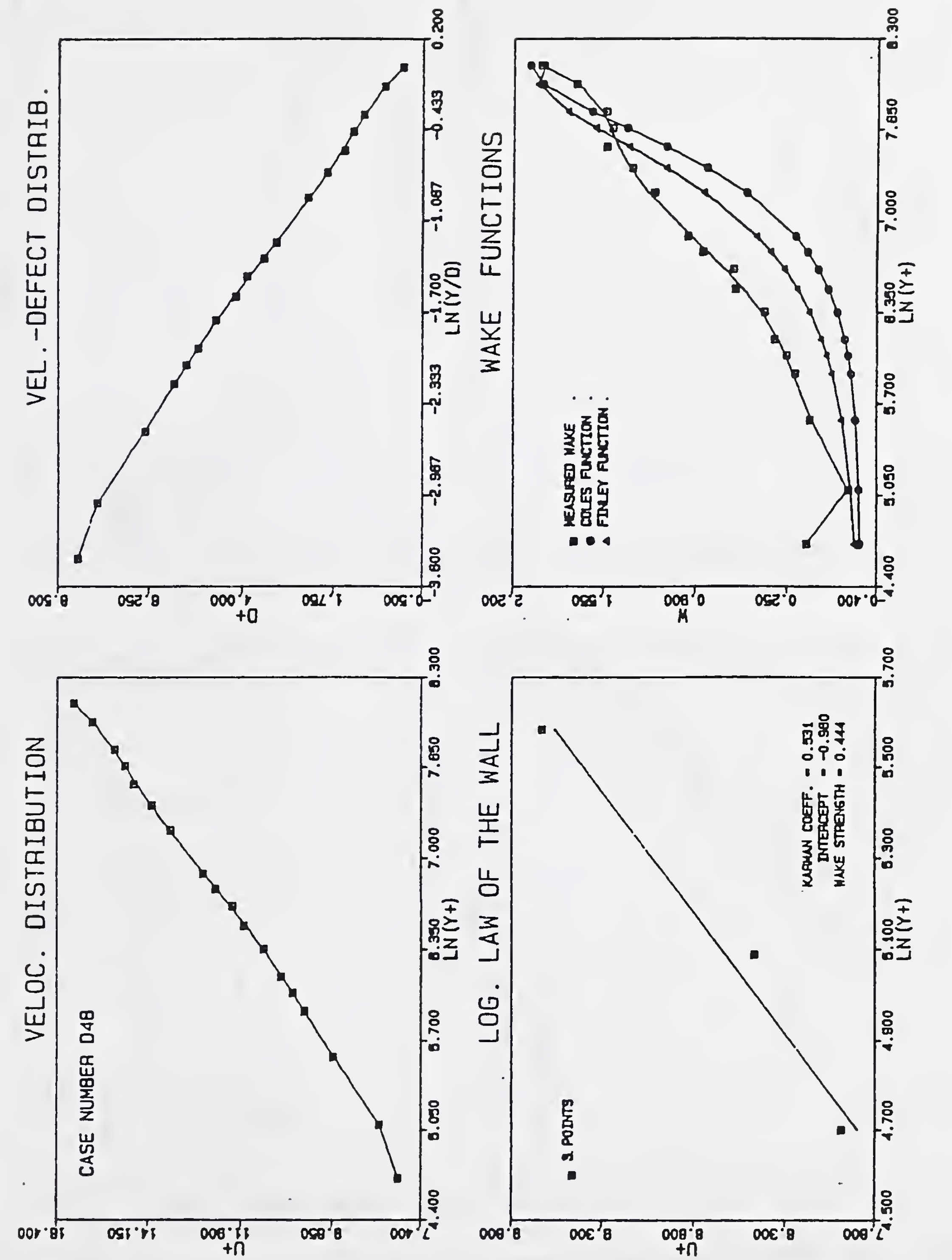


Figure 3.47: Distributions assuming null virtual origin. Case number 48.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

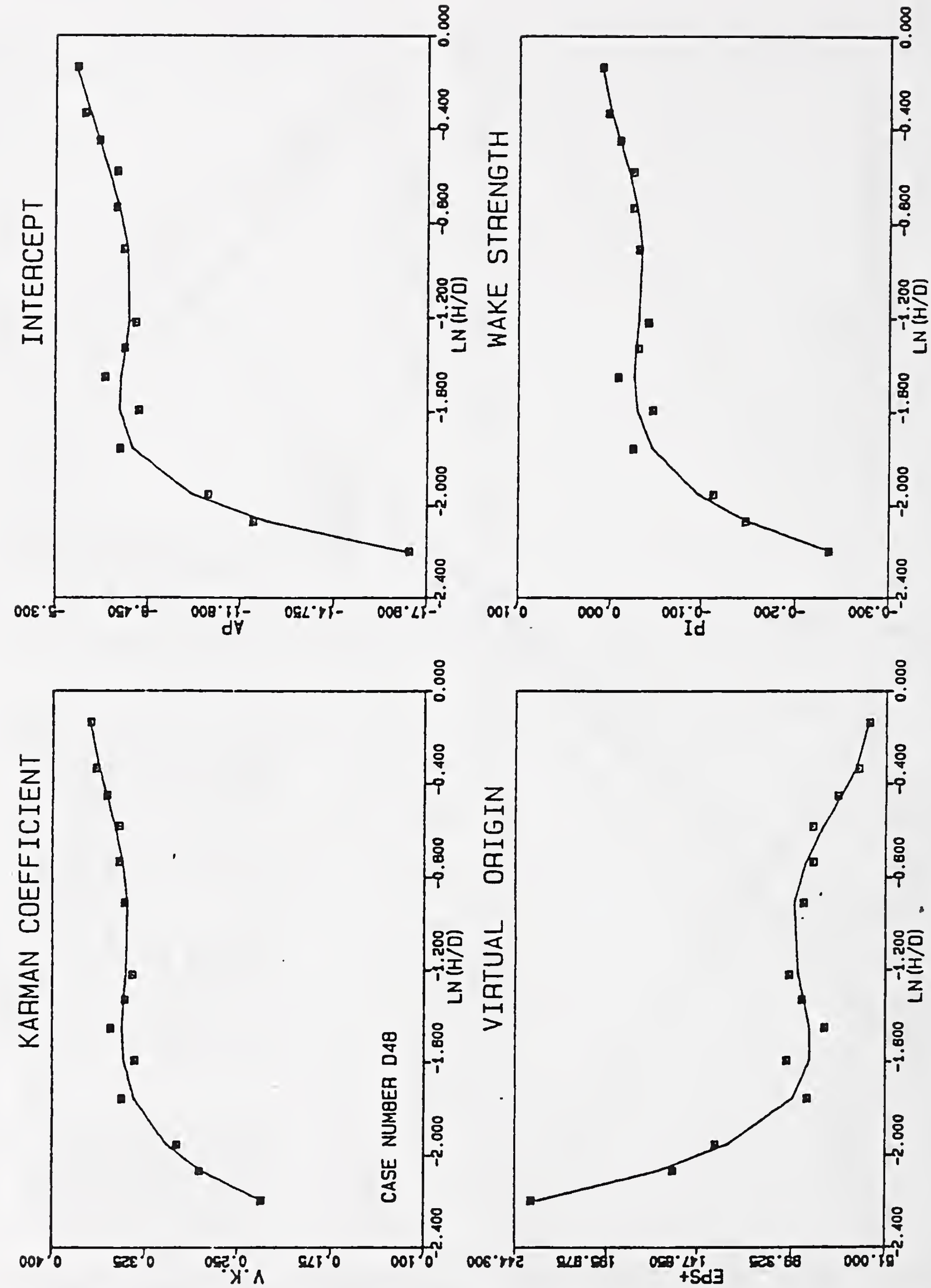


Figure 3.48: Parameter variation with the virtual-origin-search thickness H. Case number 48. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

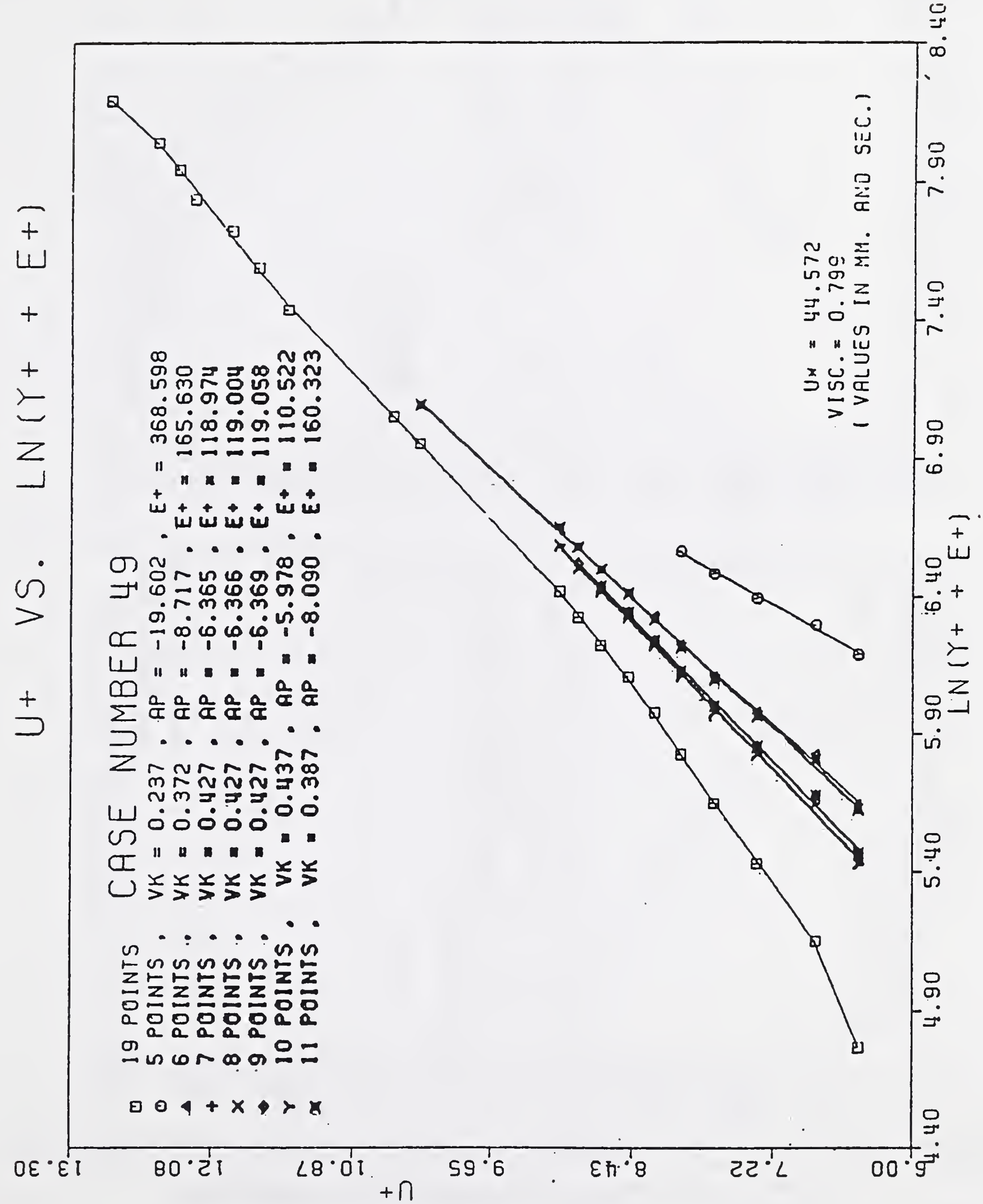


Figure 3.49 : Virtual-origin search. Case number 49.

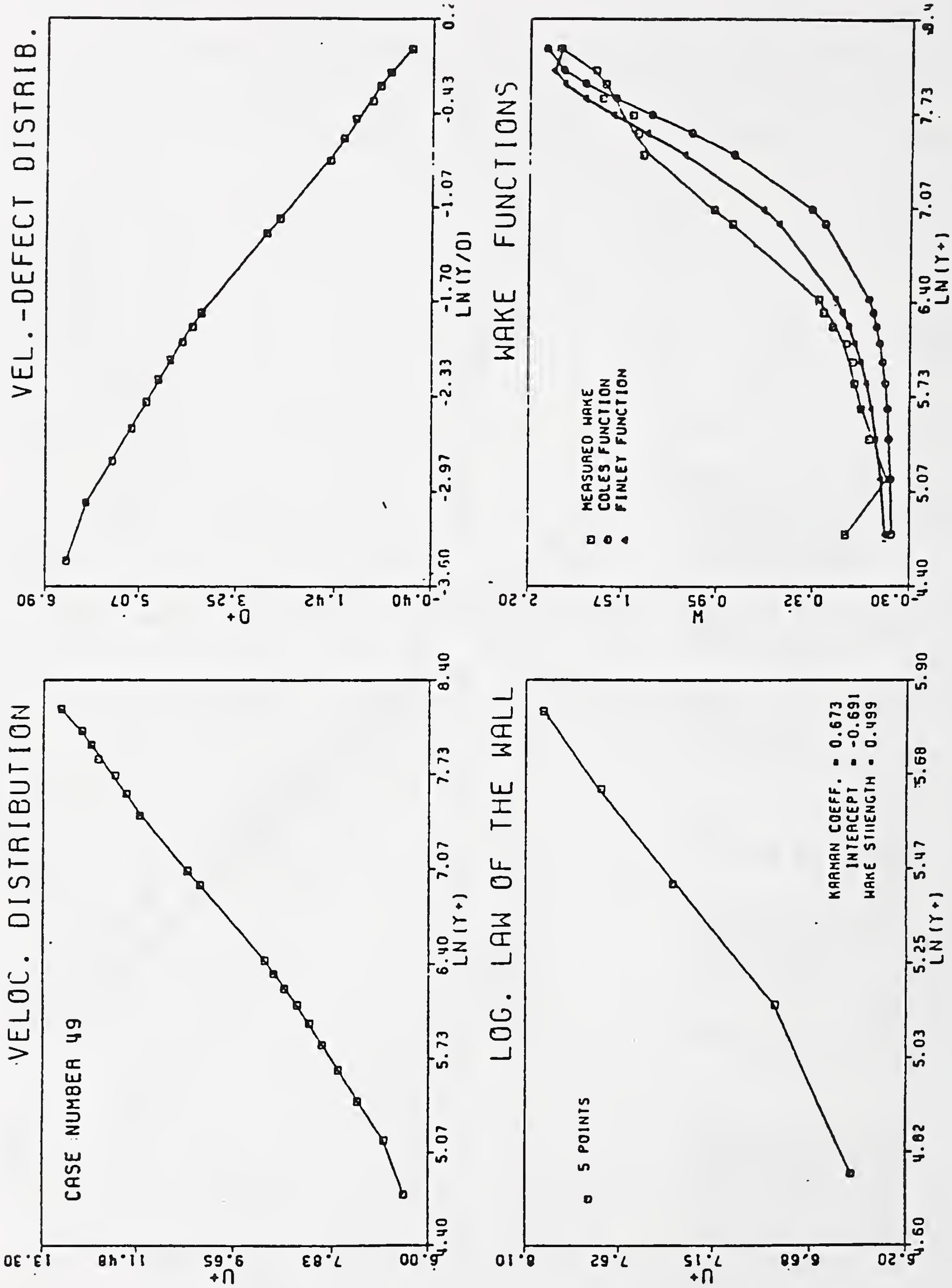


Figure 3.50: Distributions assuming null virtual origin. Case number 49.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

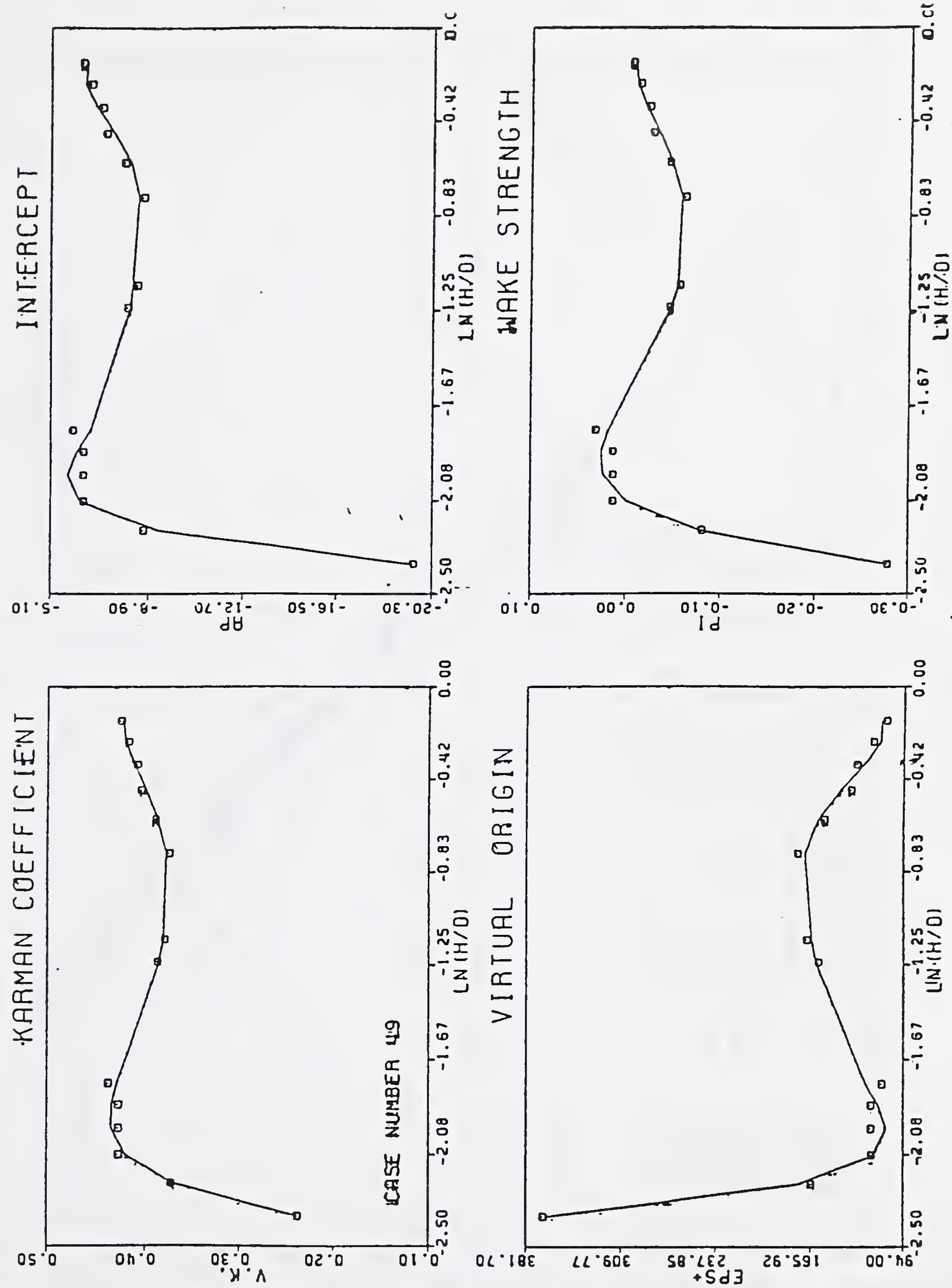


Figure 3.51: Parameter variation with the virtual-origin-search thickness H. Case number 49. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

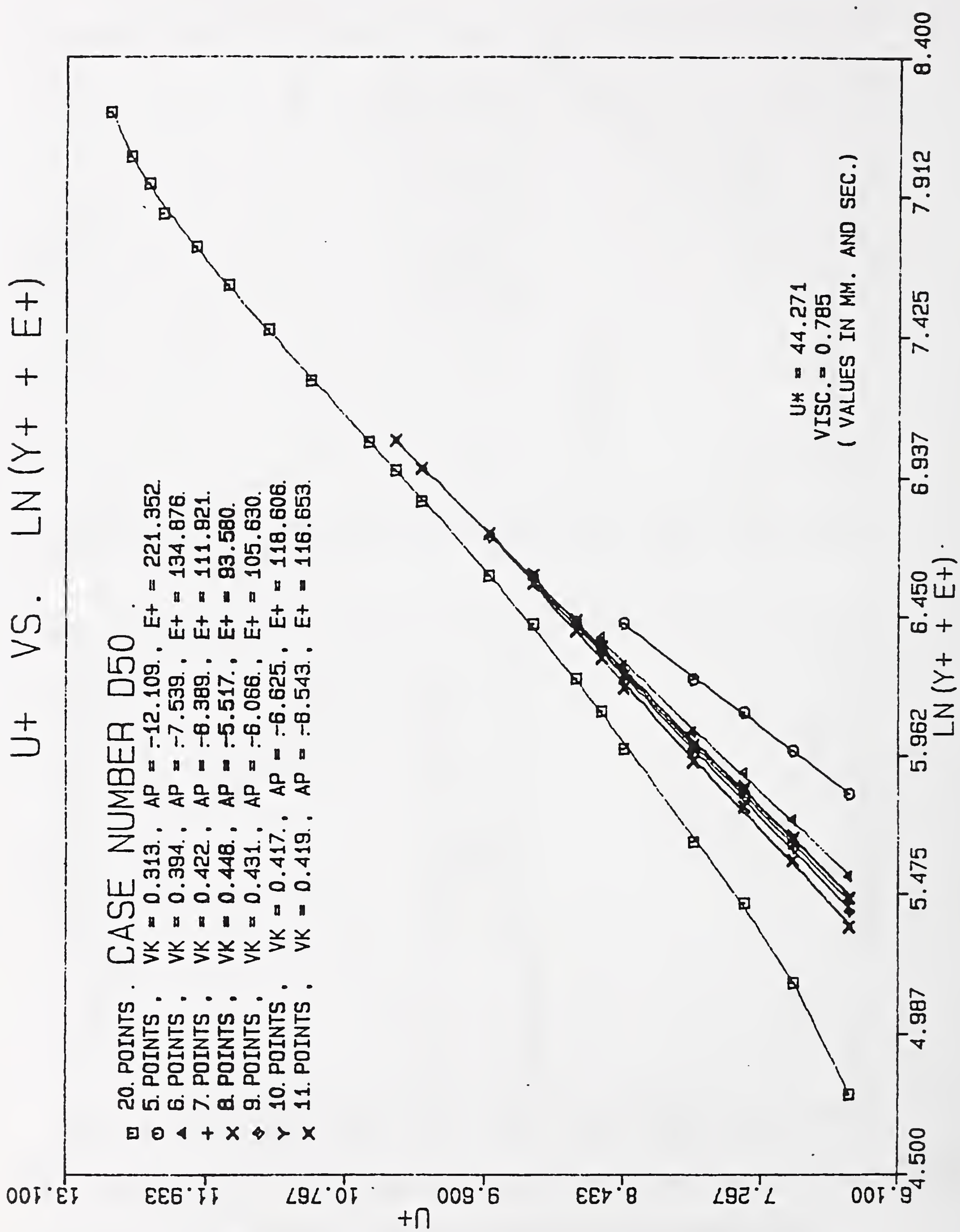


Figure 3.52 : Virtual-origin search. Case number 50.

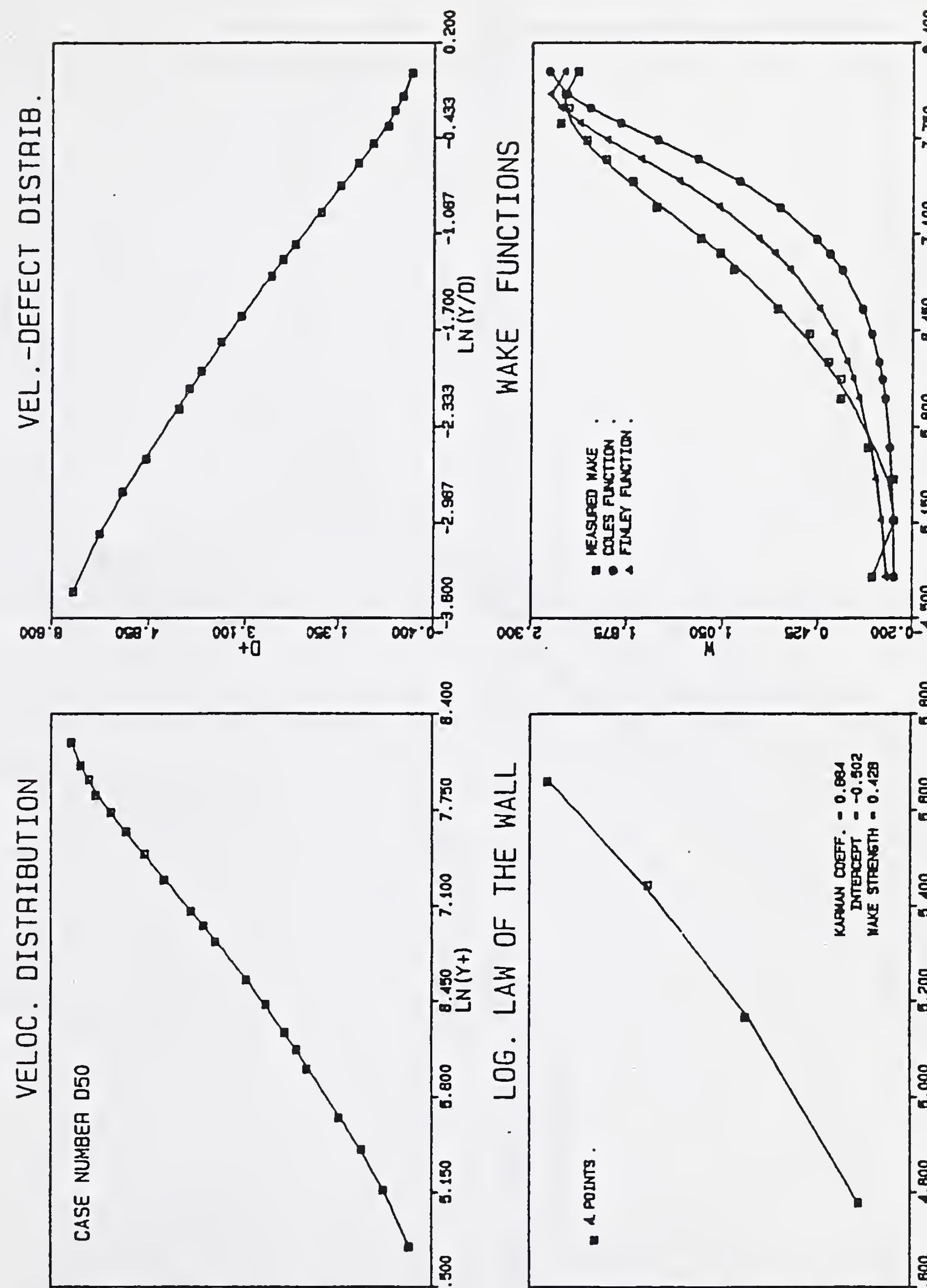


Figure 3.53: Distributions assuming null virtual origin. Case number 50.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

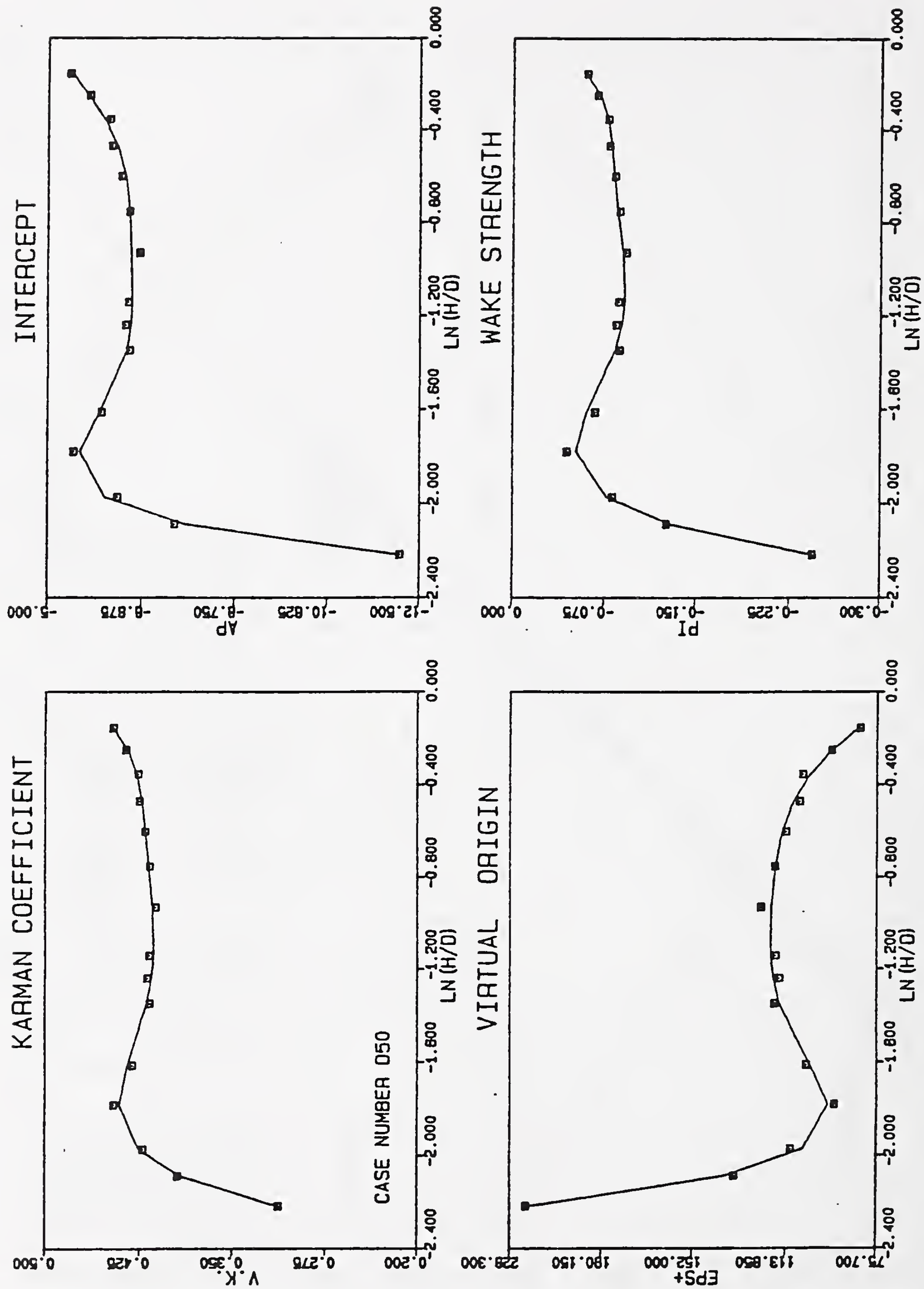


Figure 3.54: Parameter variation with the virtual-origin-search thickness H. Case number 50. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

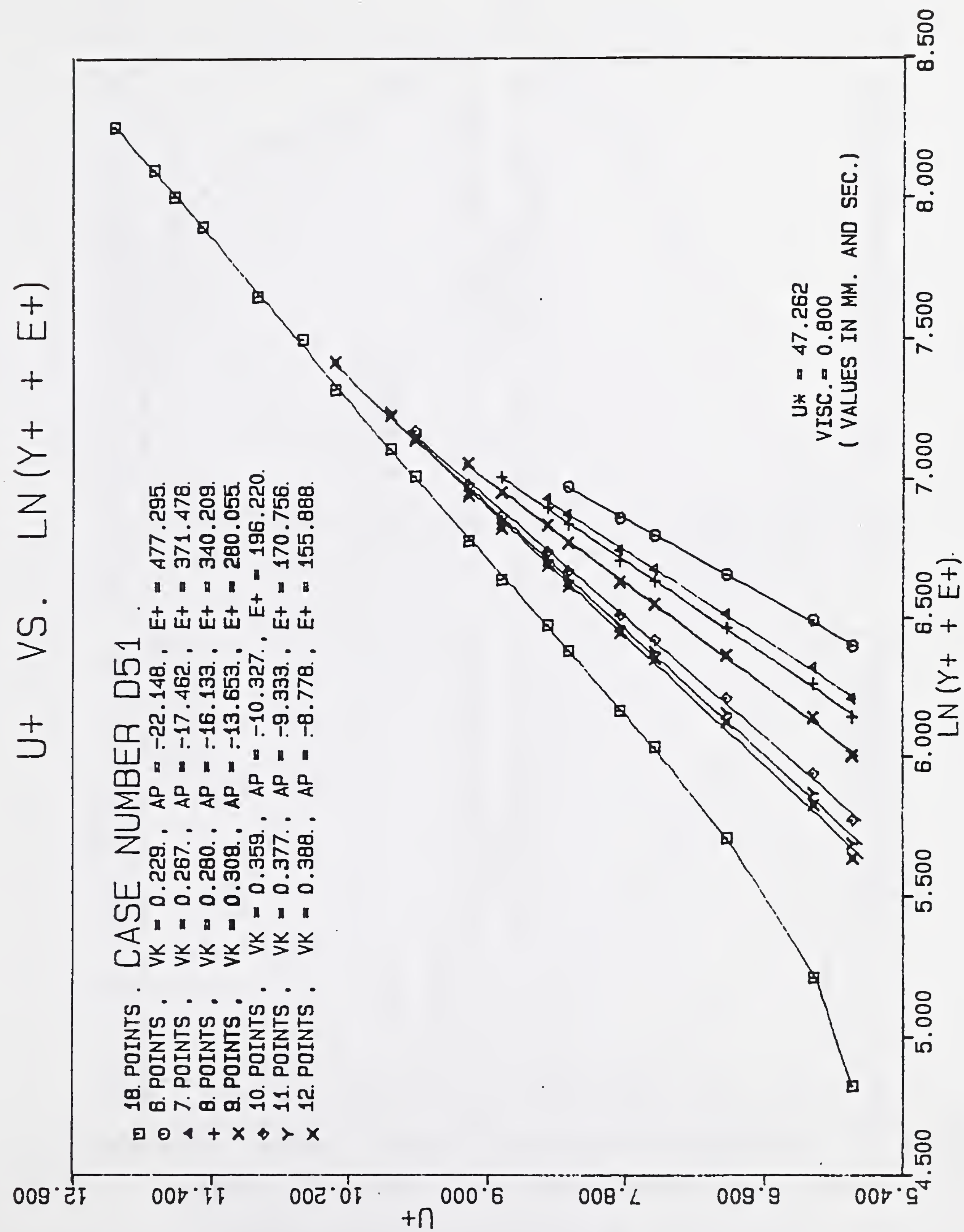


Figure 3.55 : Virtual-origin search. Case number 51.

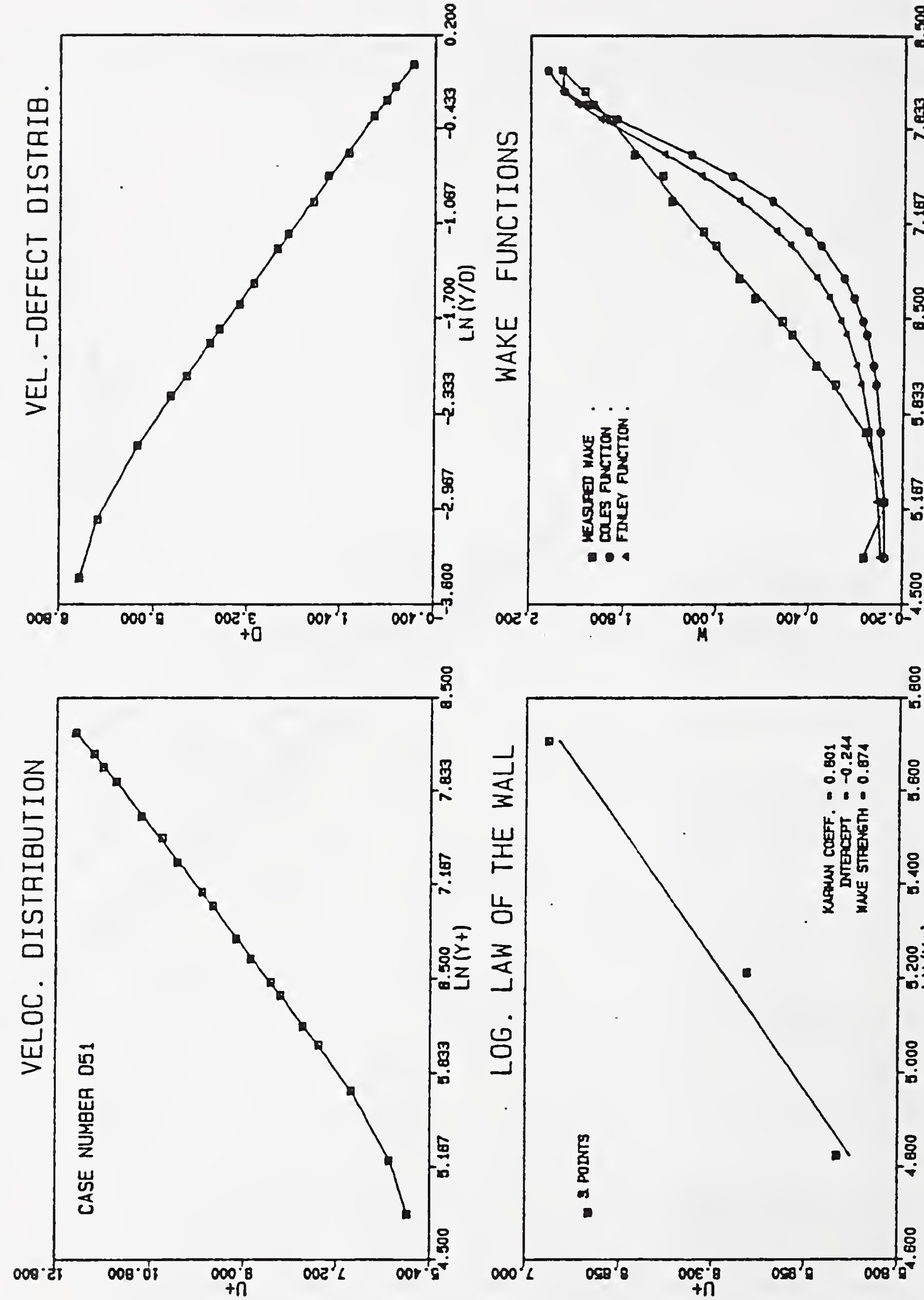


Figure 3.56: Distributions assuming null virtual origin. Case number 51.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

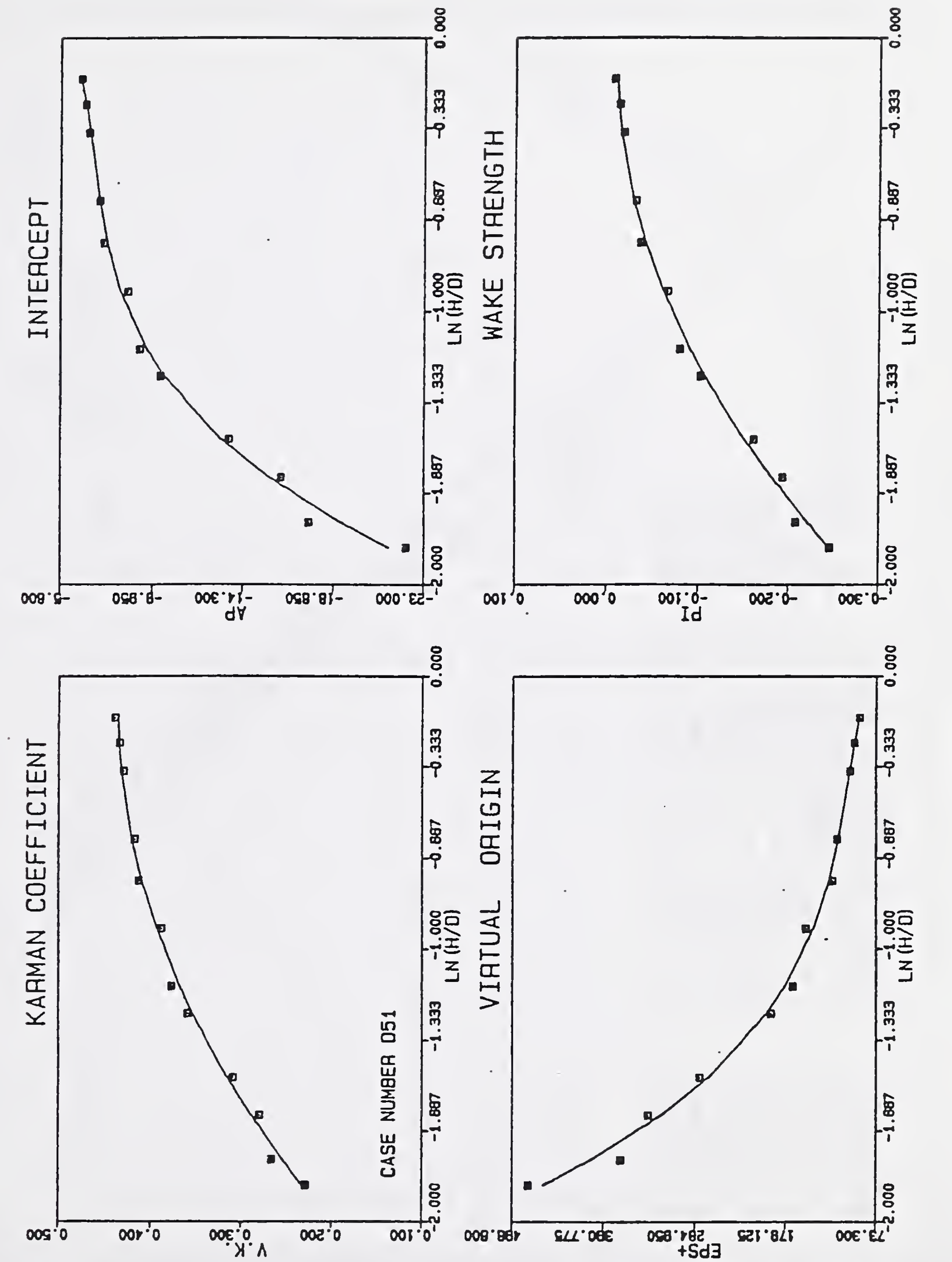


Figure 3.57: Parameter variation with the virtual-origin-search thickness H. Case number 51. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

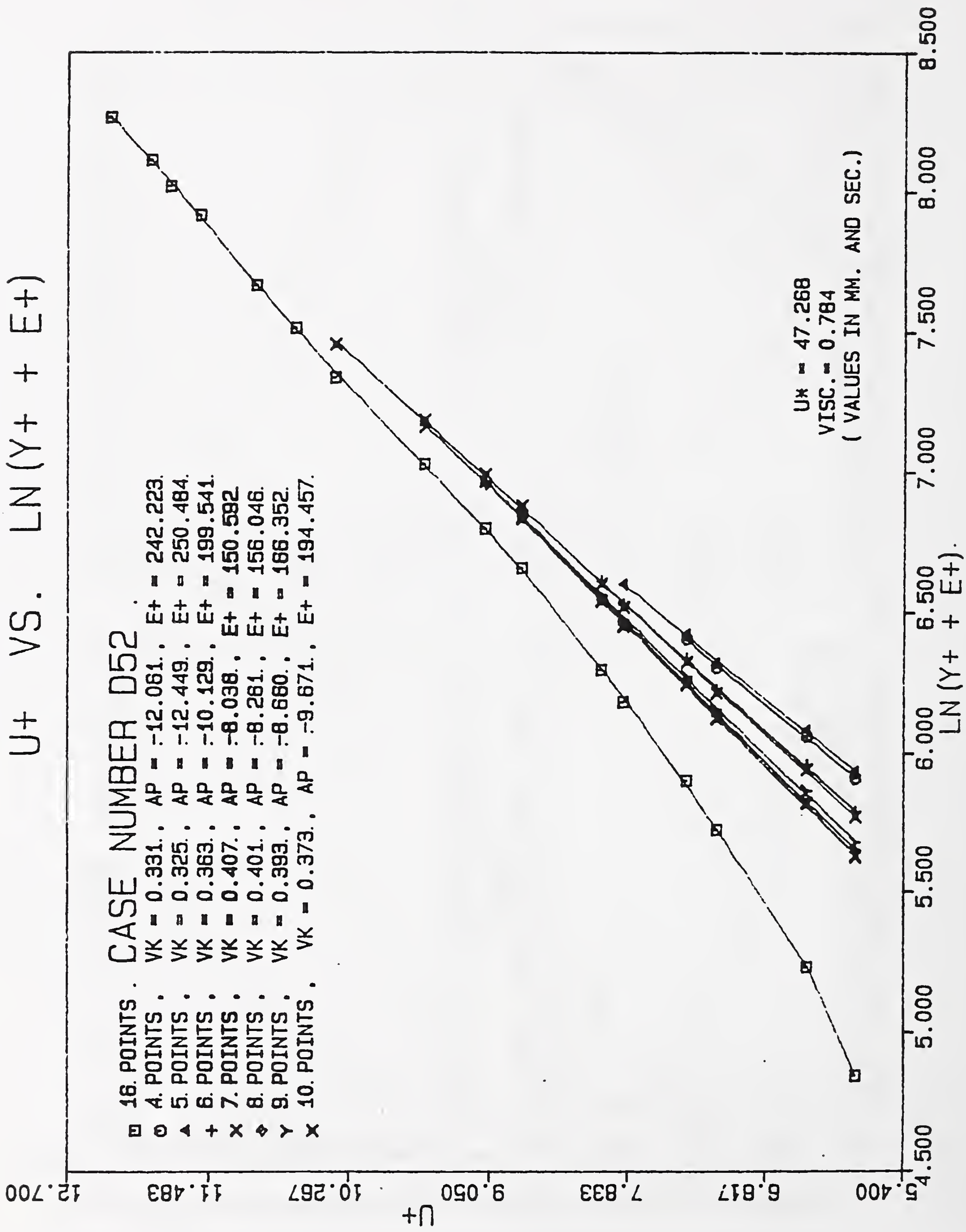


Figure 3.58 : Virtual-origin search. Case number 52.

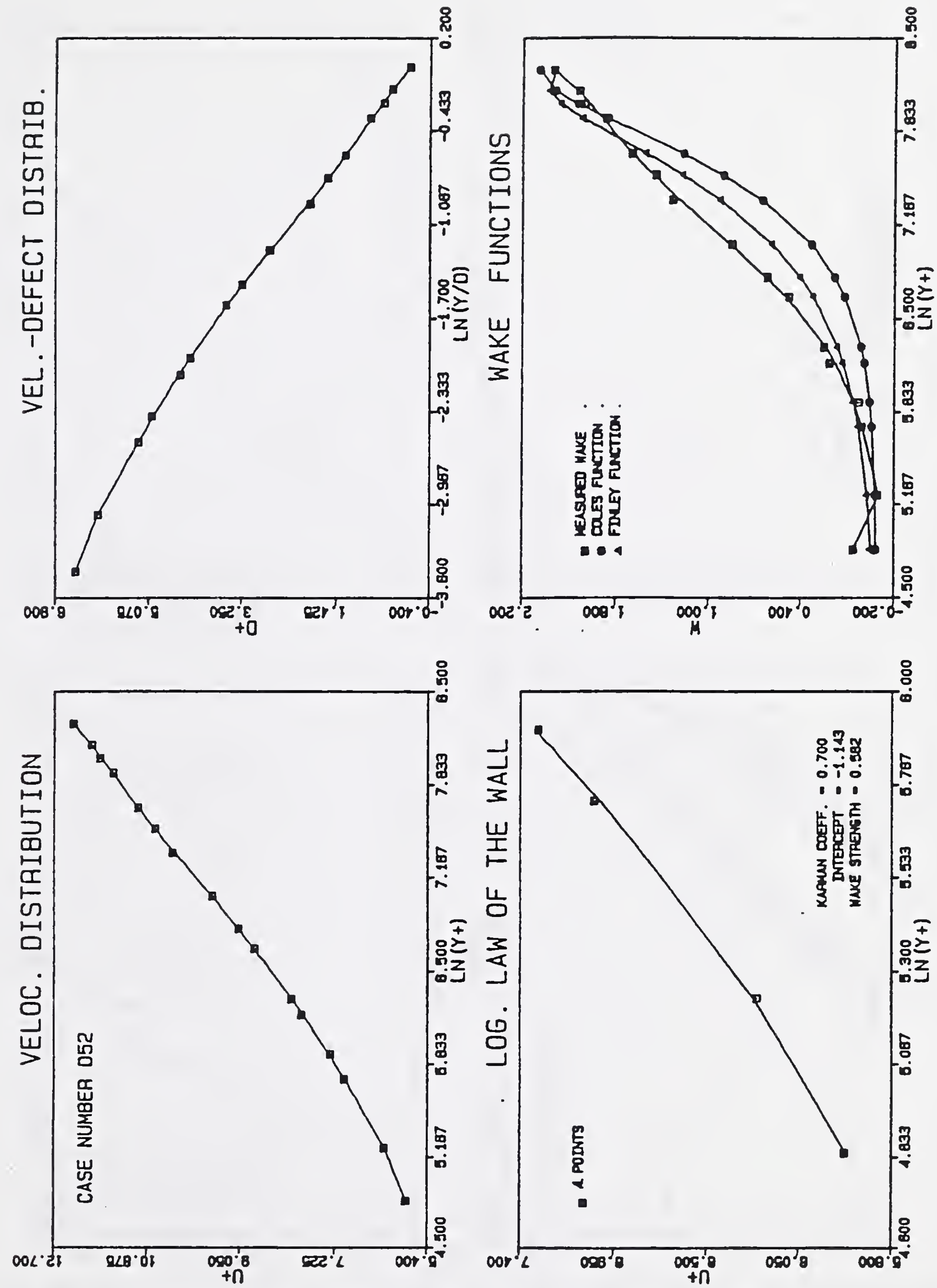


Figure 3.59: Distributions assuming null virtual origin. Case number 52.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

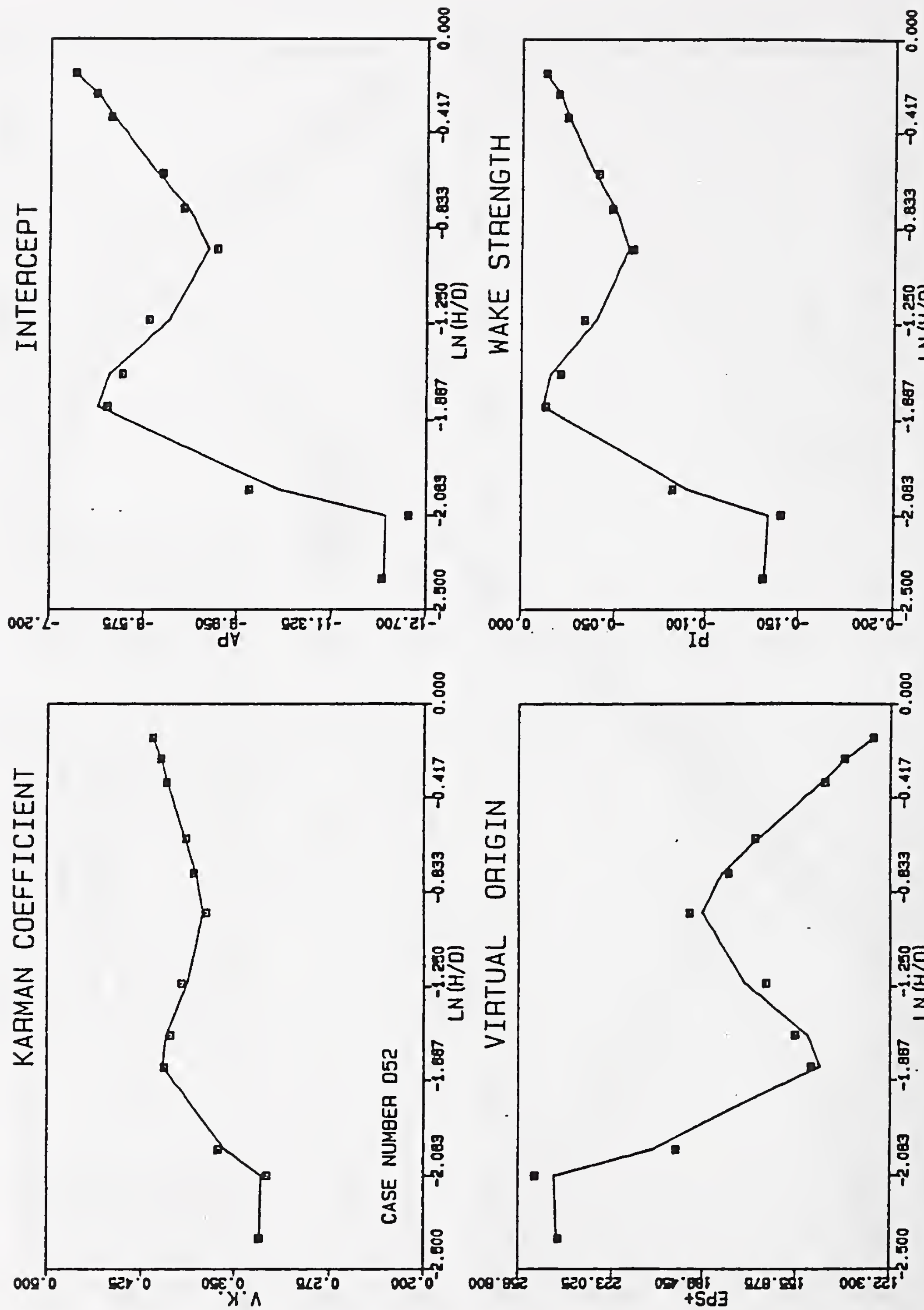


Figure 3.60: Parameter variation with the virtual-origin-search thickness H. Case number 52. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

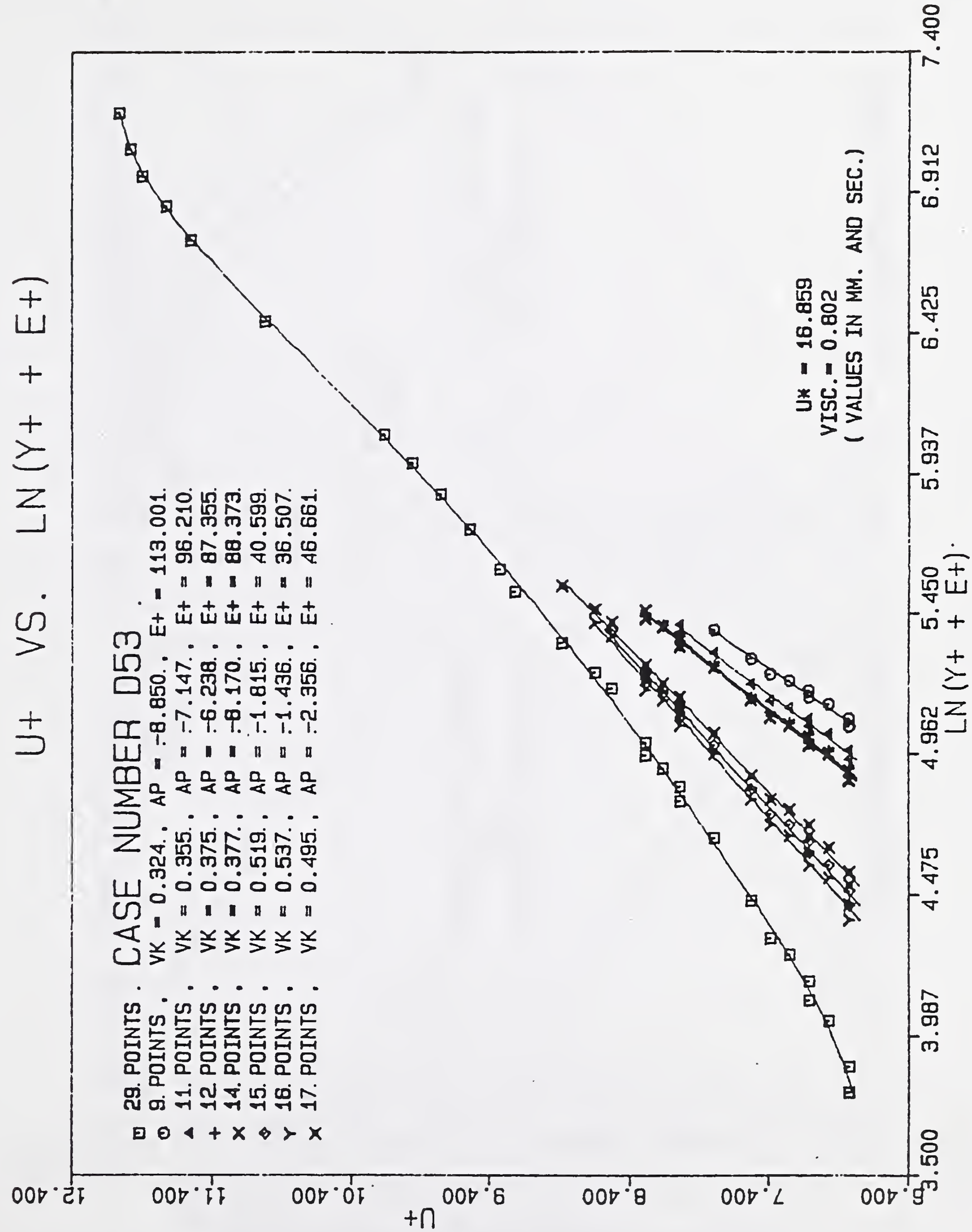


Figure 3.61 : Virtual-origin search. Case number 53.

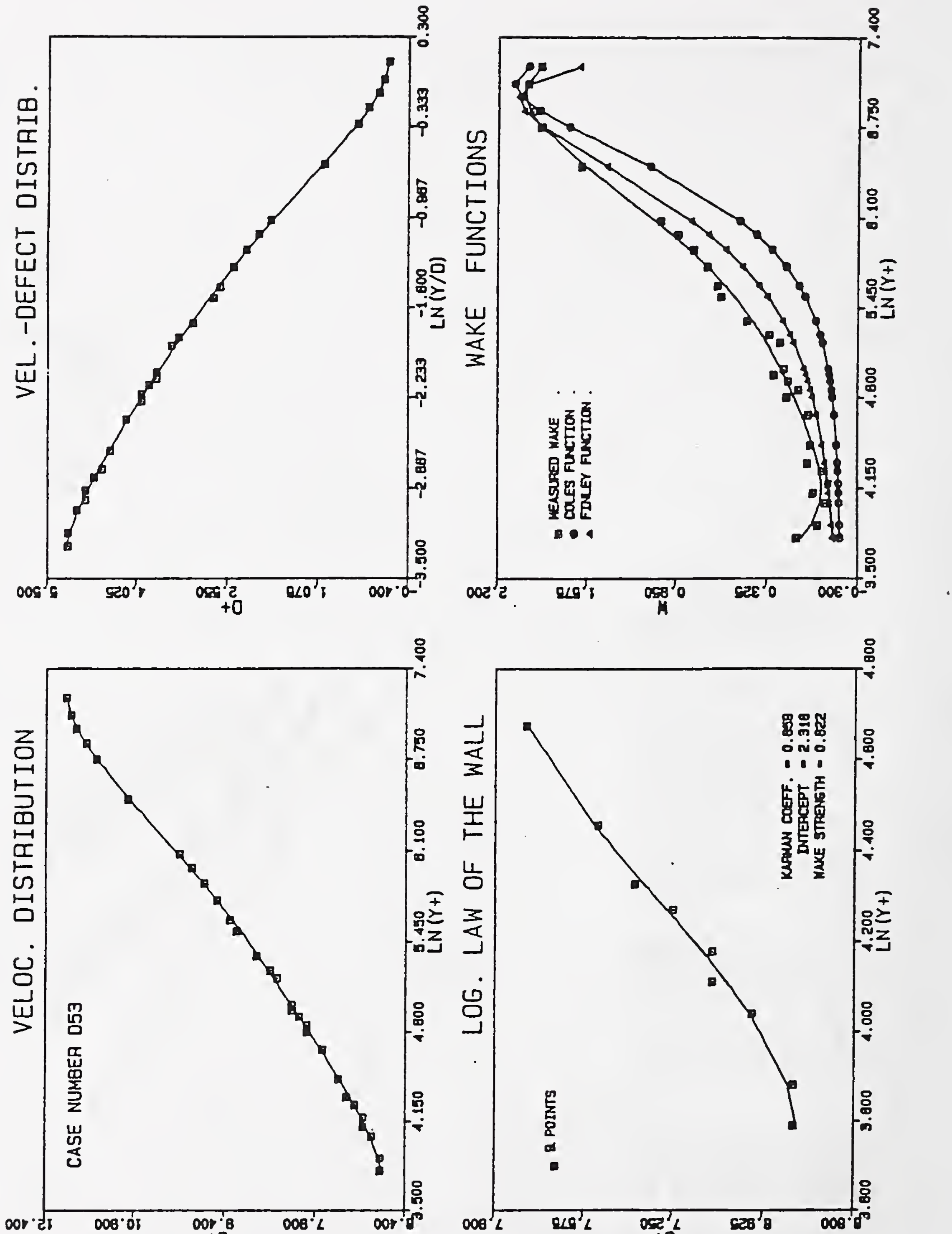


Figure 3.62: Distributions assuming null virtual origin. Case number 53.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

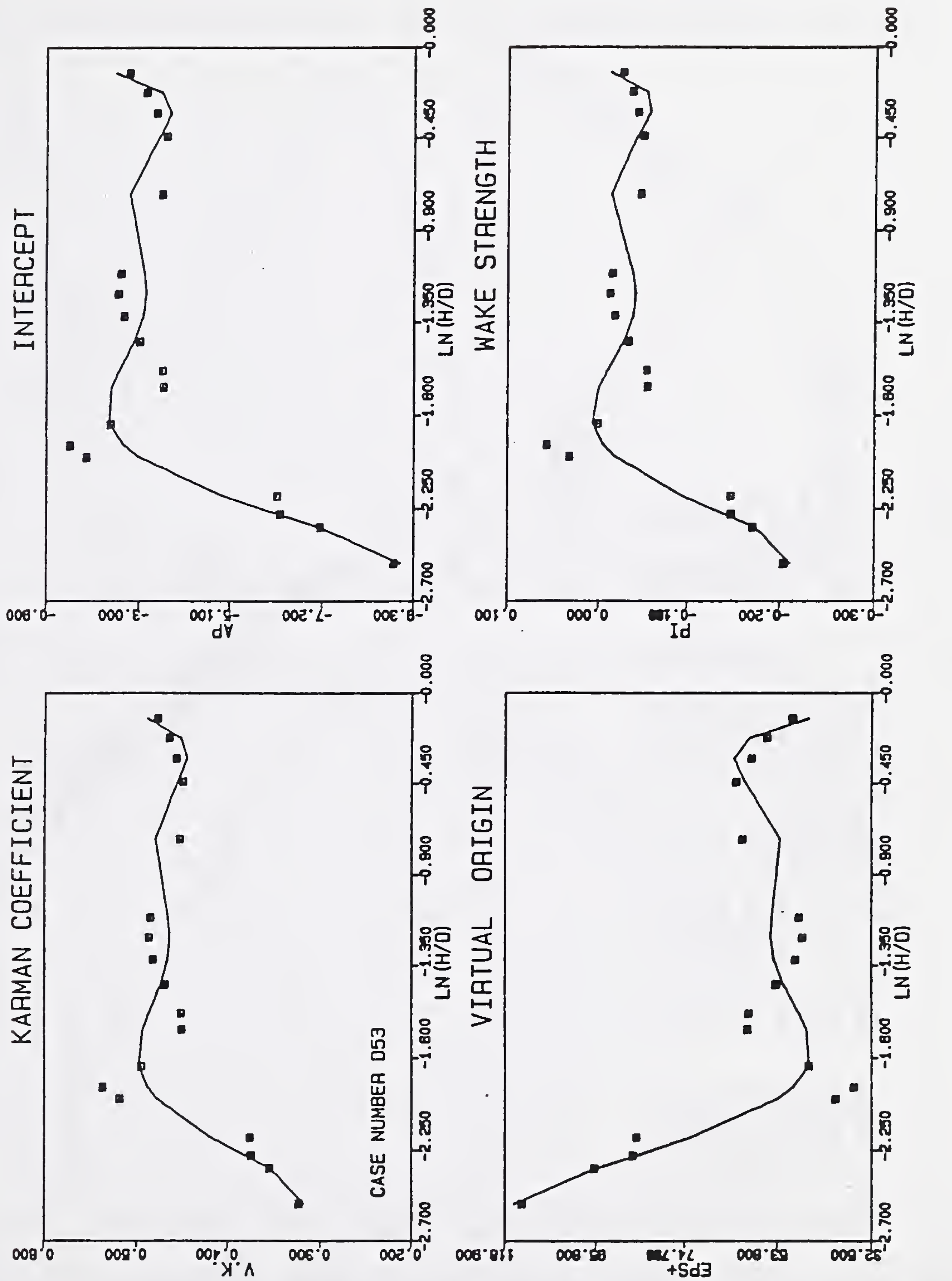


Figure 3.63: Parameter variation with the virtual-origin-search thickness H. Case number 53. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

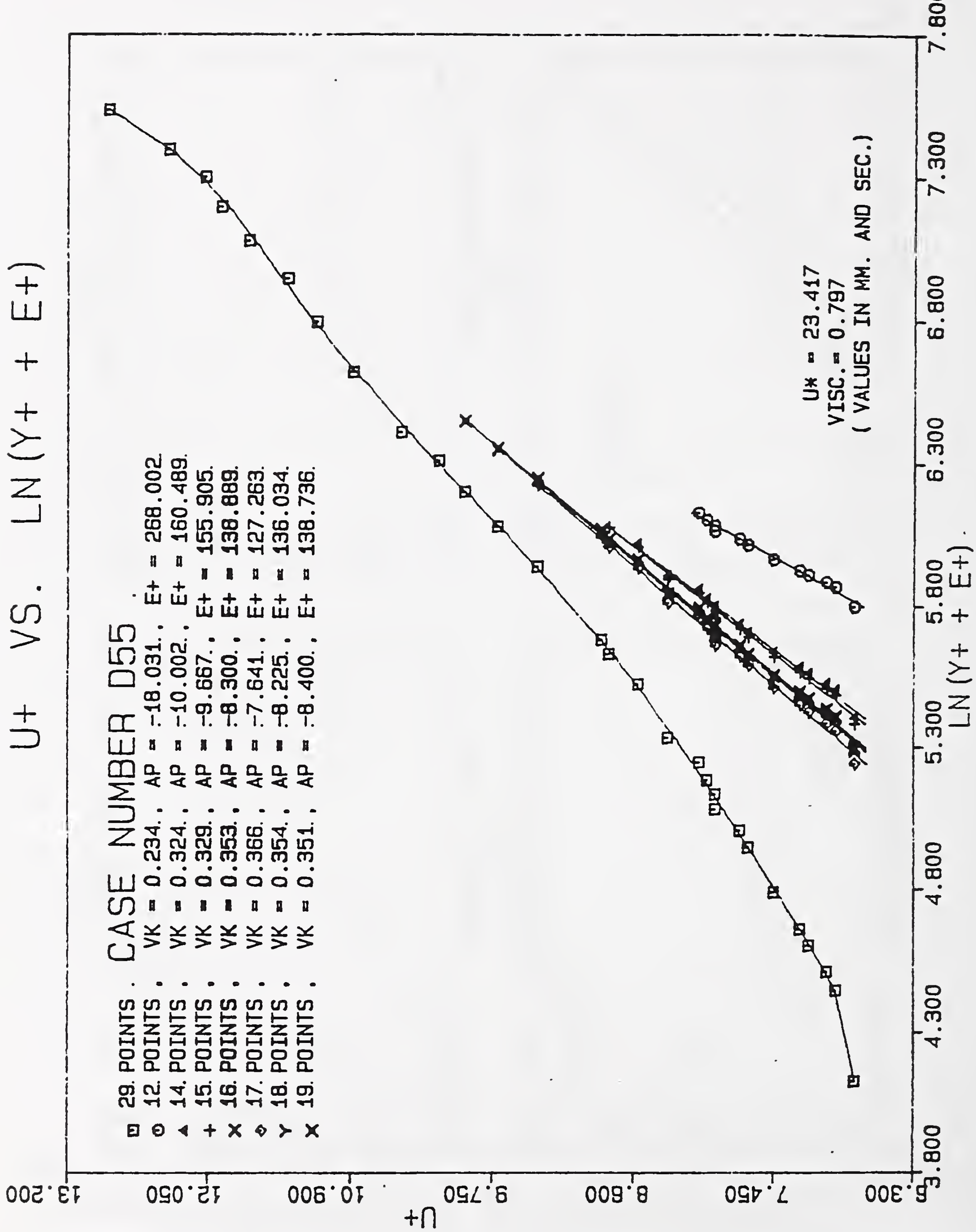


Figure 3.64 : Virtual-origin search. Case number 55.

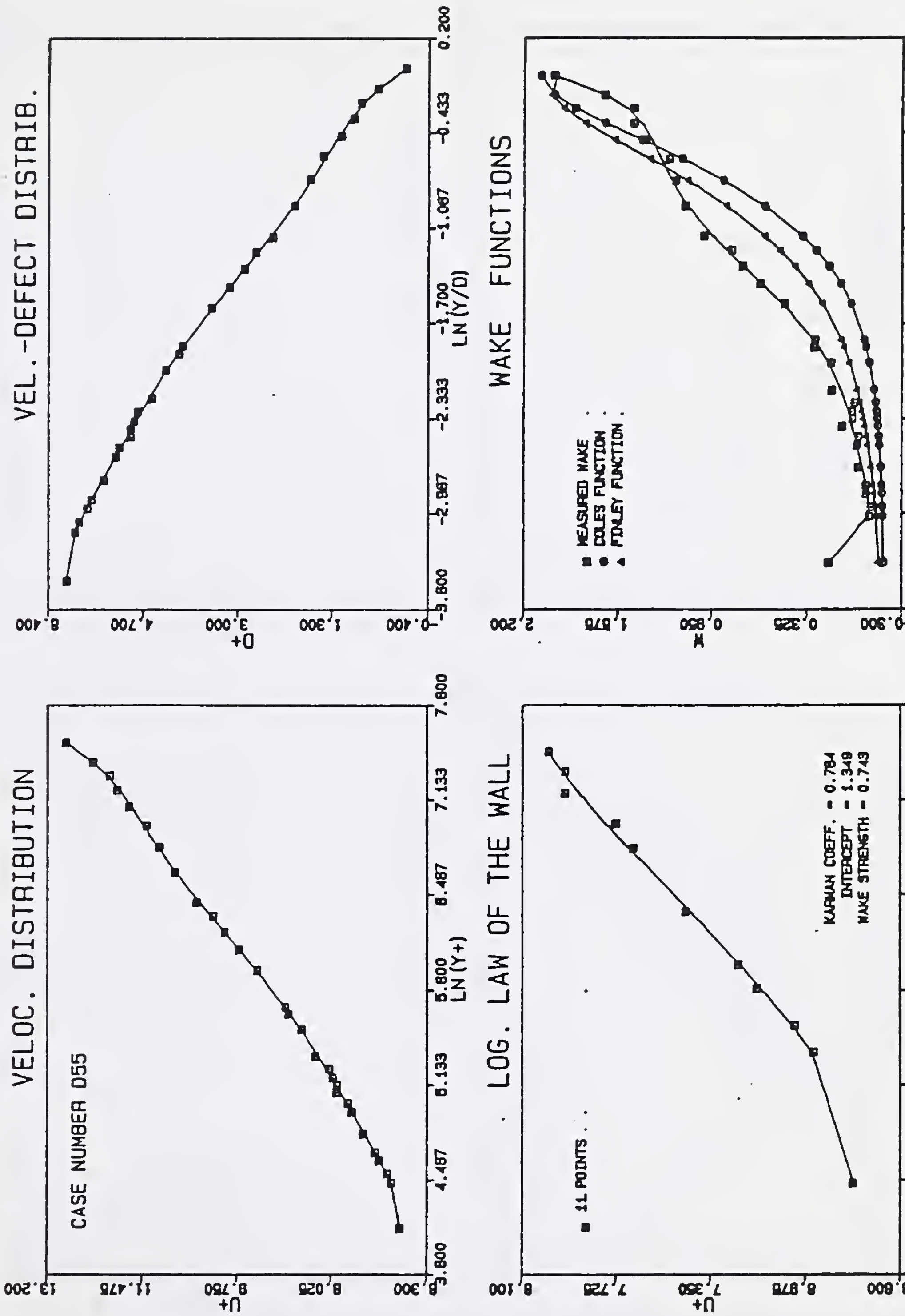


Figure 3.65: Distributions assuming null virtual origin. Case number 55.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

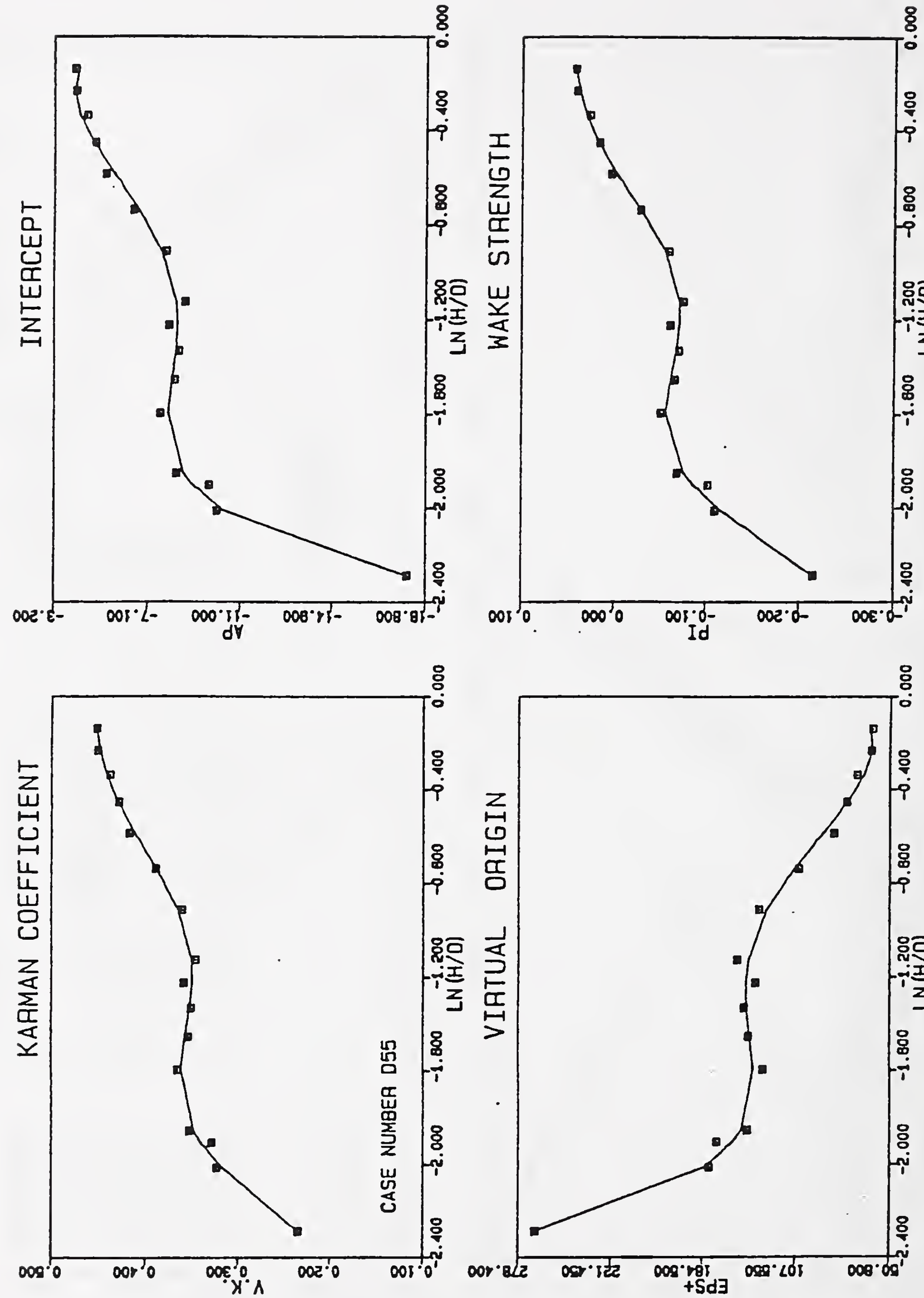


Figure 3.66: Parameter variation with the virtual-origin-search thickness H. Case number 55. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

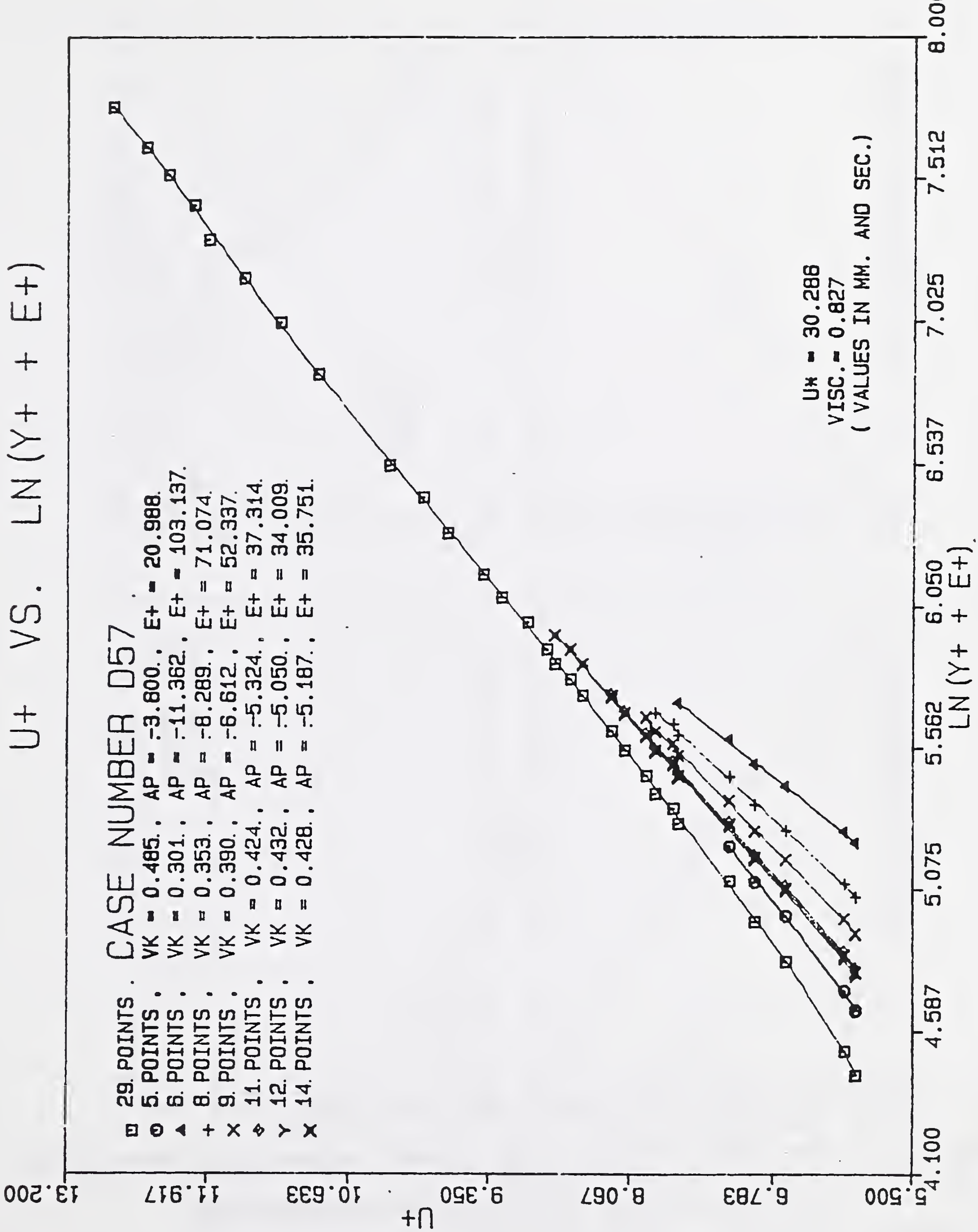


Figure 3.67 : Virtual-origin search. Case number 57.

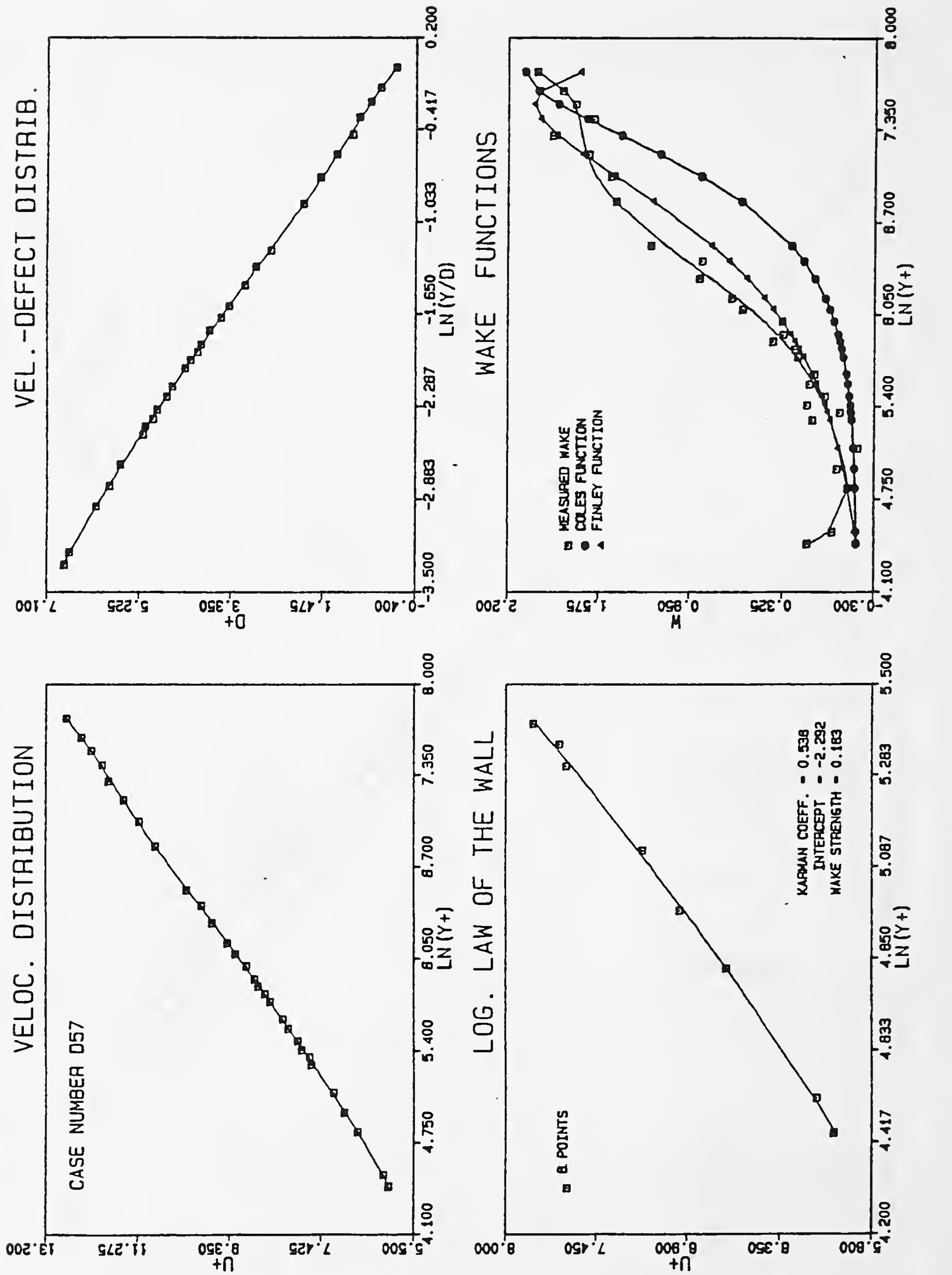


Figure 3.68: Distributions assuming null virtual origin. Case number 57.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

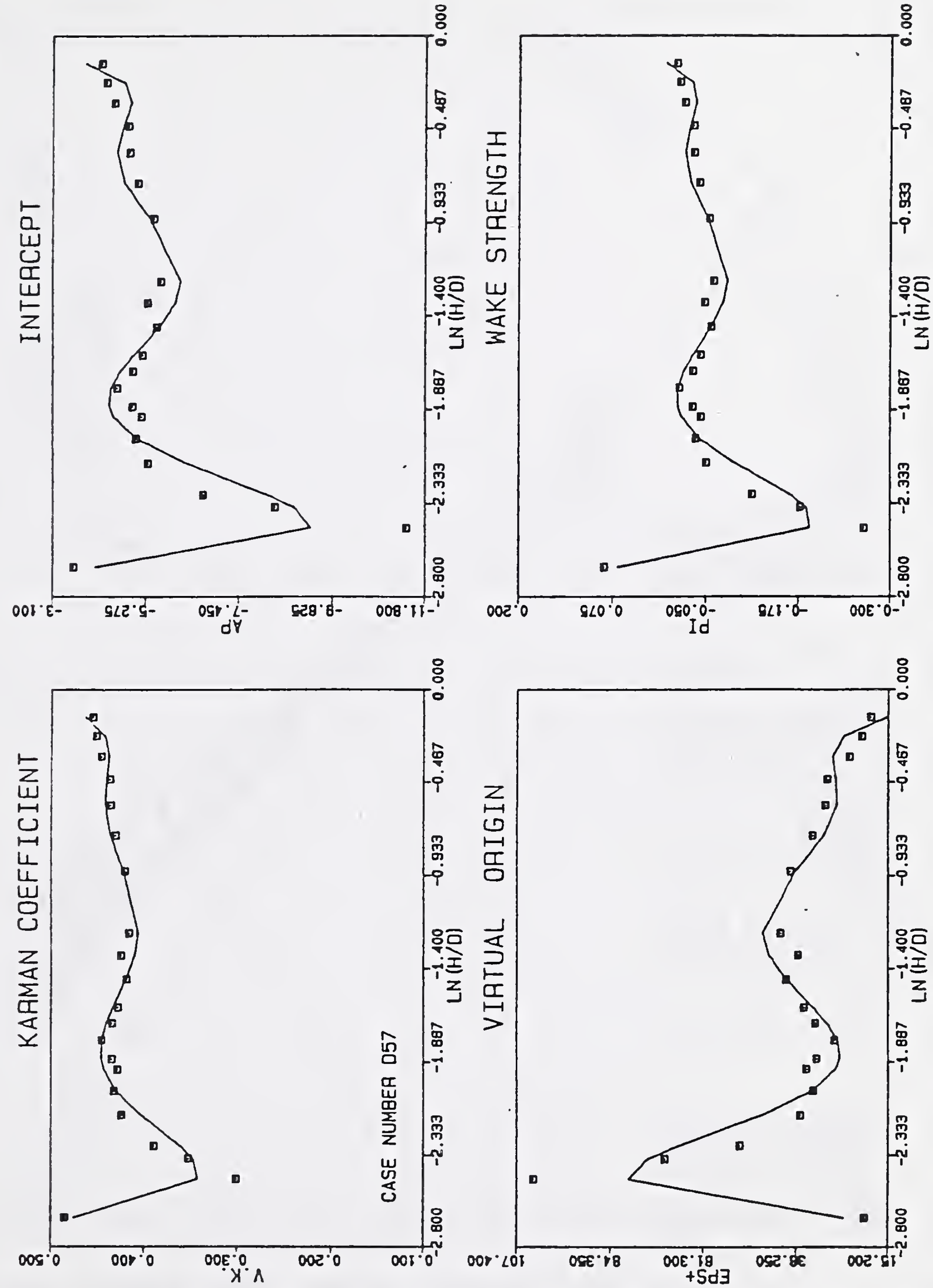


Figure 3.69: Parameter variation with the virtual-origin-search thickness H. Case number 57. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

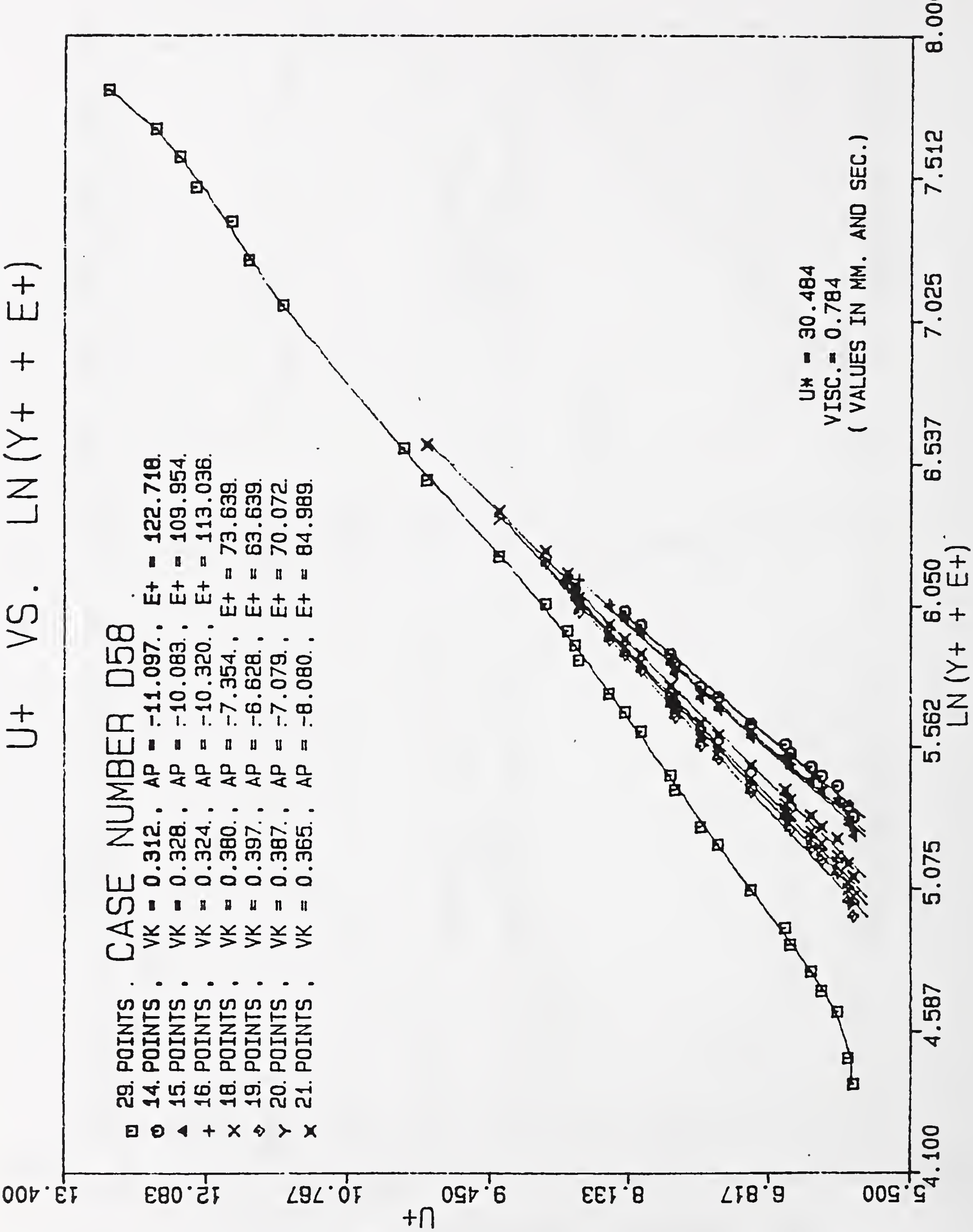


Figure 3.70 : Virtual-origin search. Case number 58.

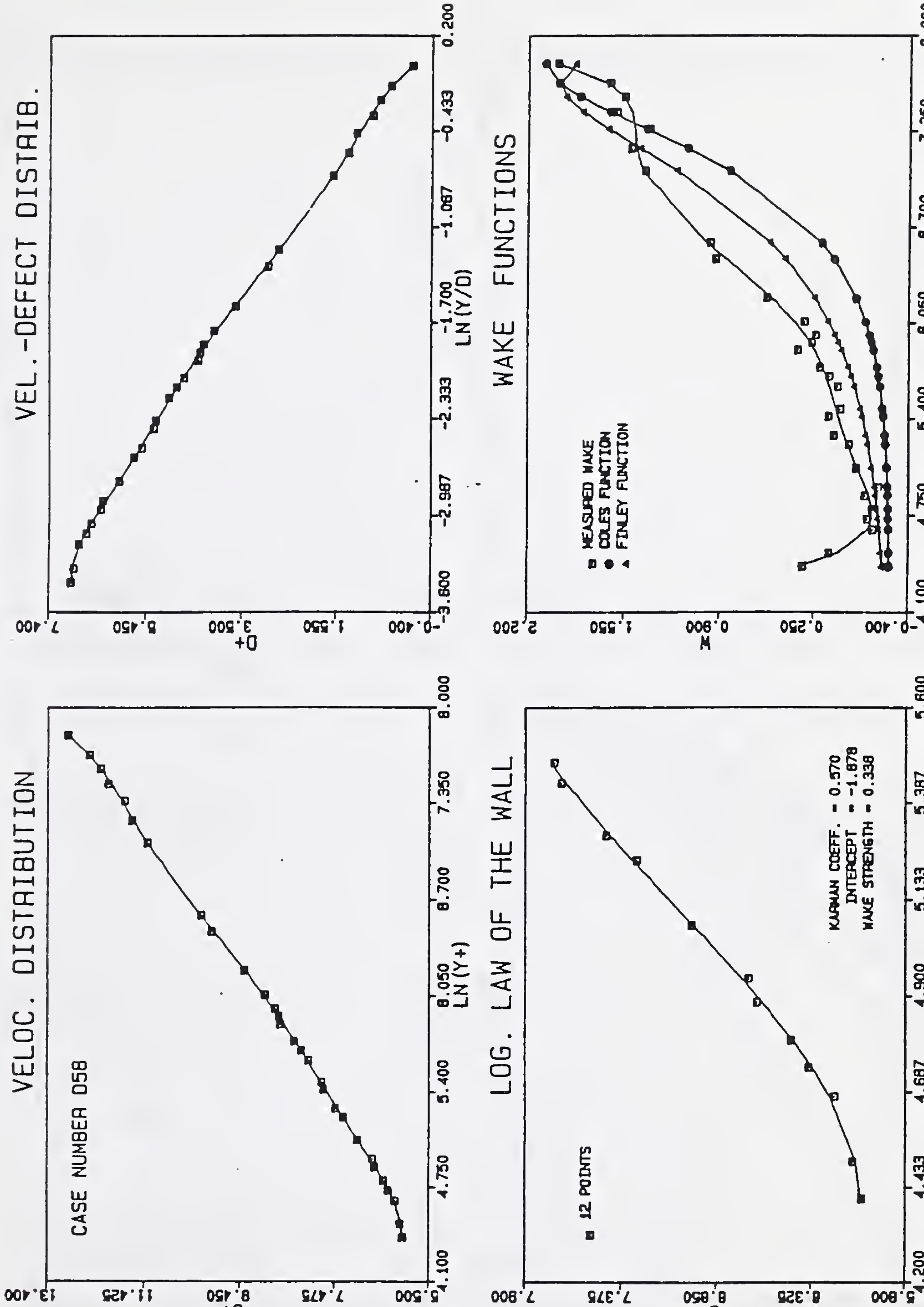


Figure 3.71: Distributions assuming null virtual origin. Case number 58.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

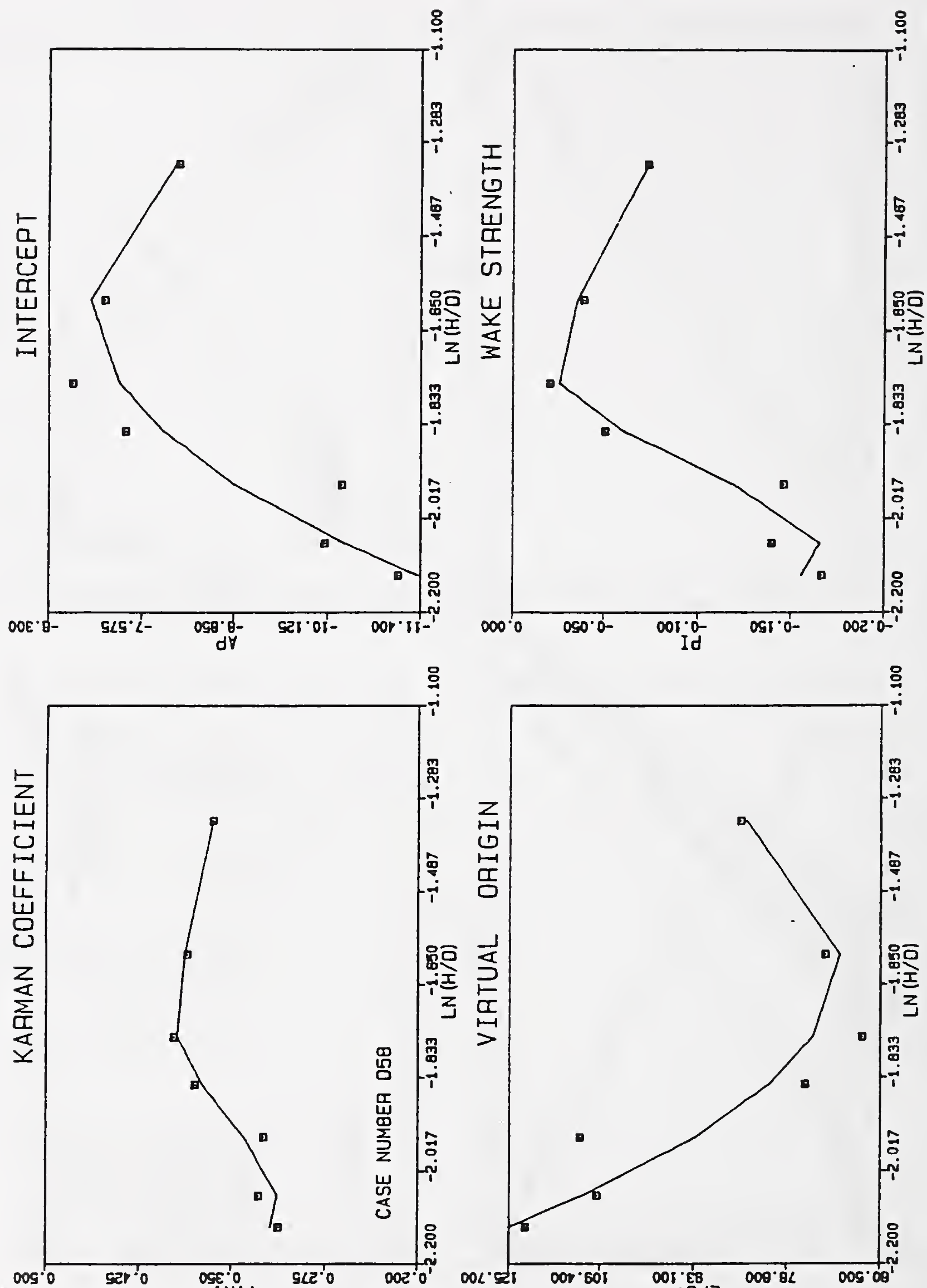


Figure 3.72: Parameter variation with the virtual-origin-search thickness H. Case number 58. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

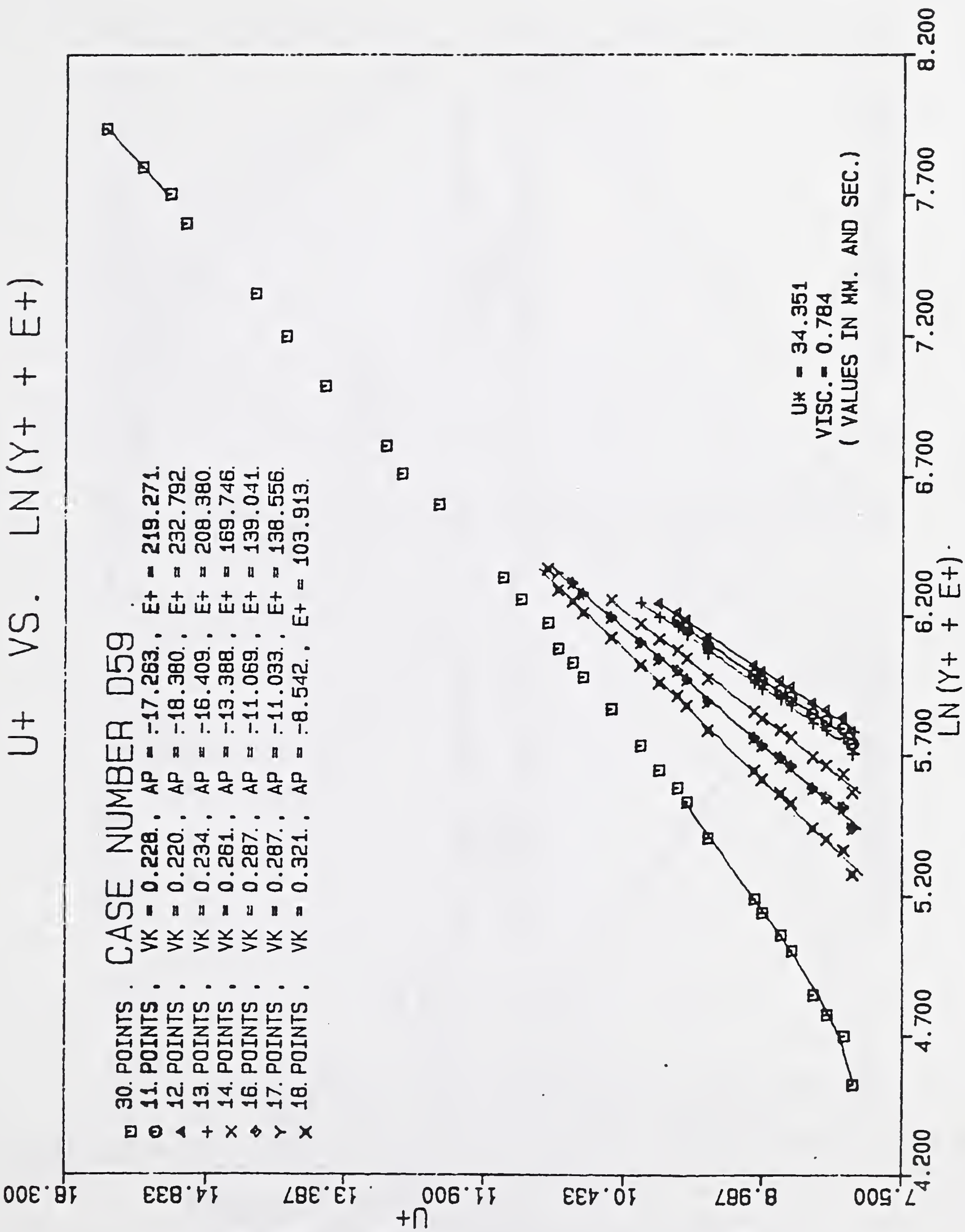


Figure 3.73 : Virtual-origin search. Case number 59.

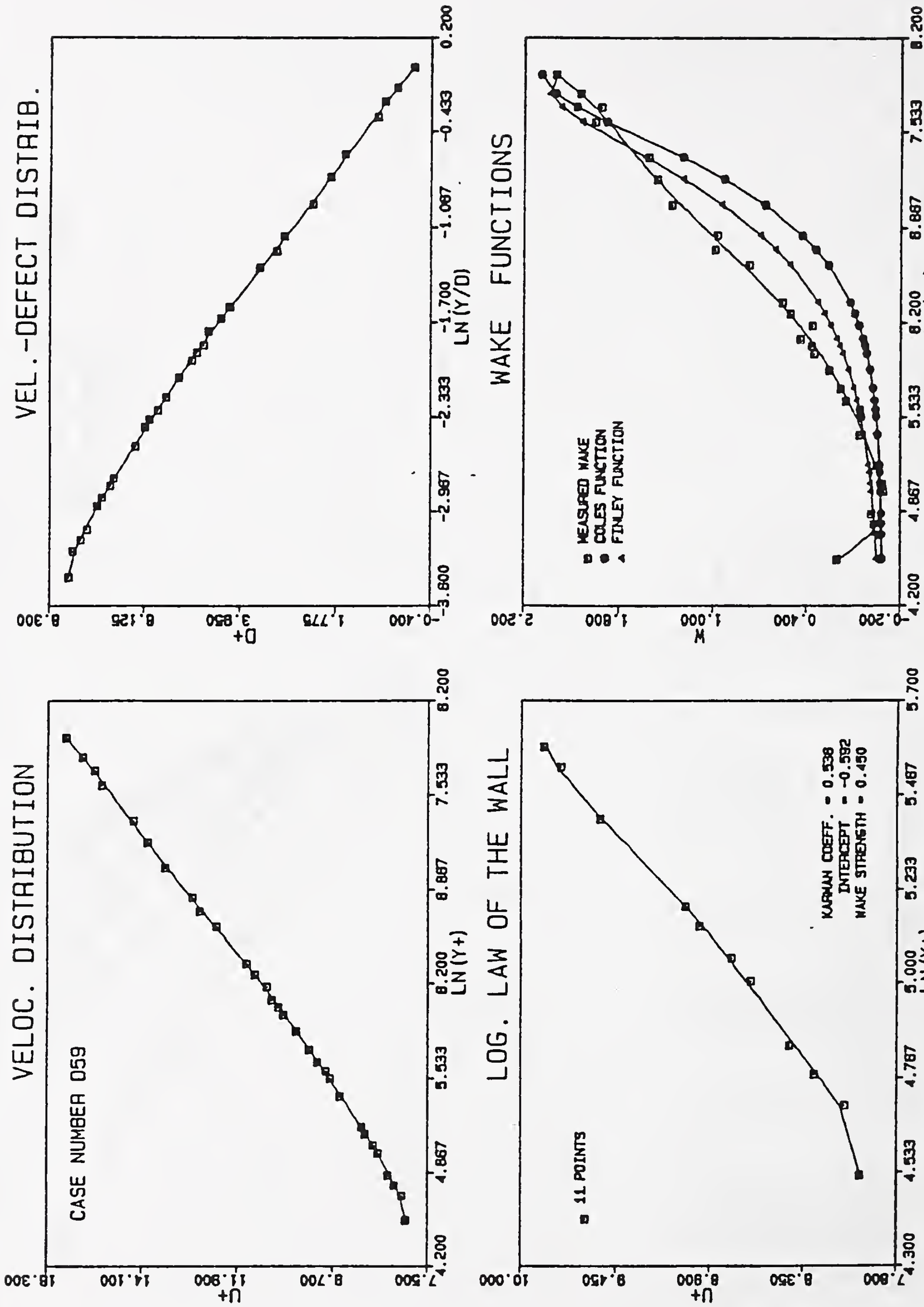


Figure 3.74: Distributions assuming null virtual origin. Case number 59.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

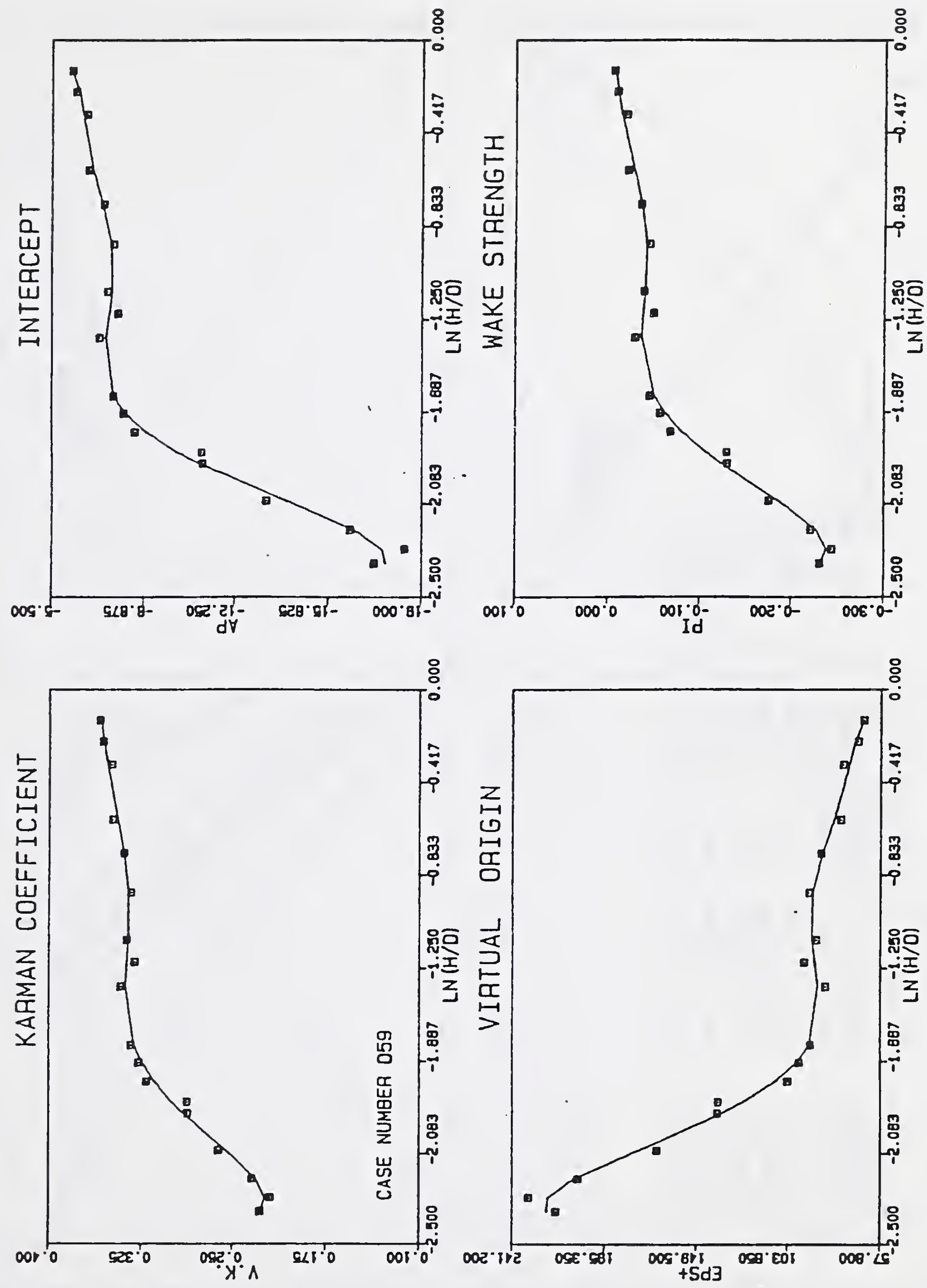


Figure 3.75: Parameter variation with the virtual-origin-search thickness H. Case number 59. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

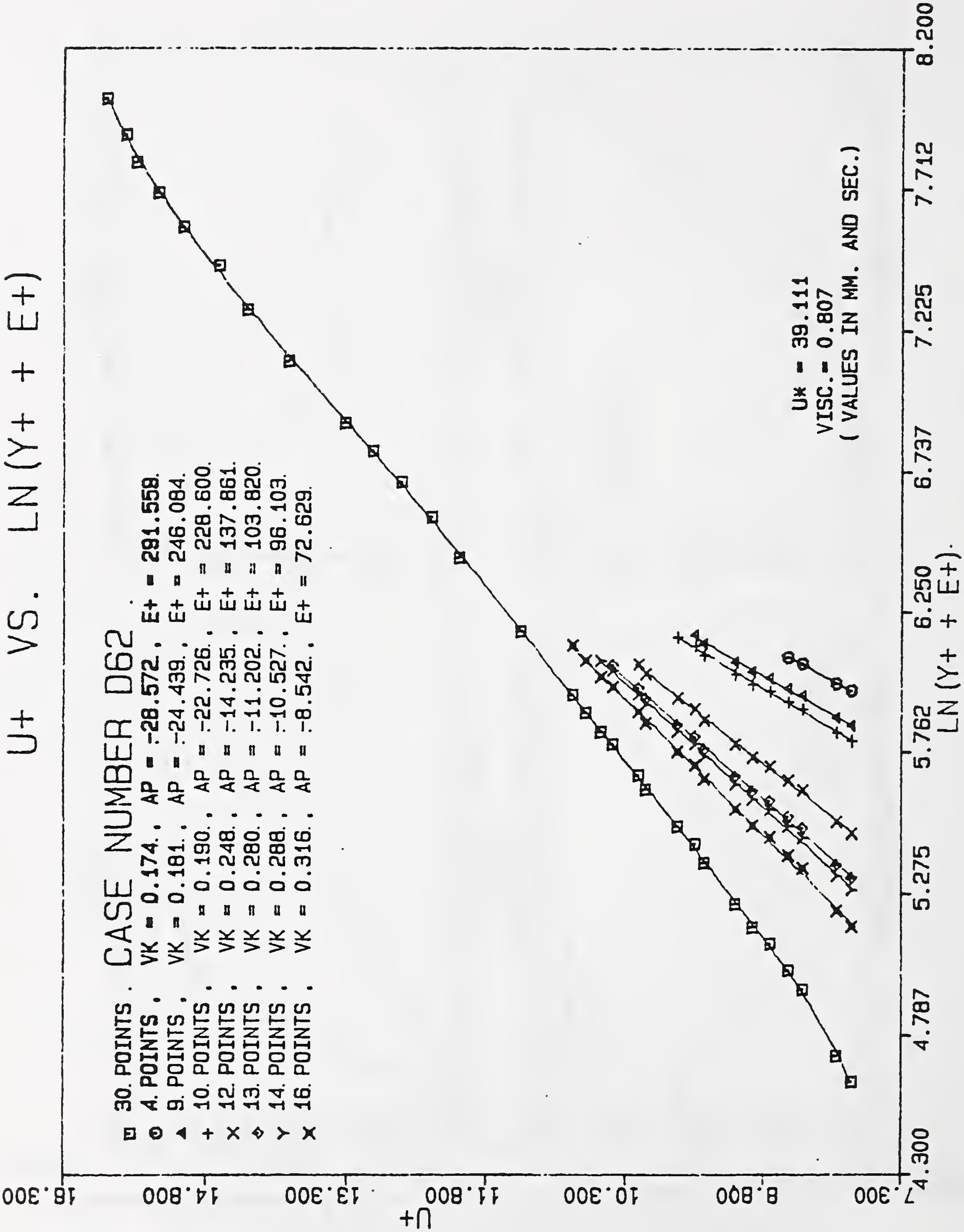


Figure 3.76 : Virtual-origin search. Case number 62.

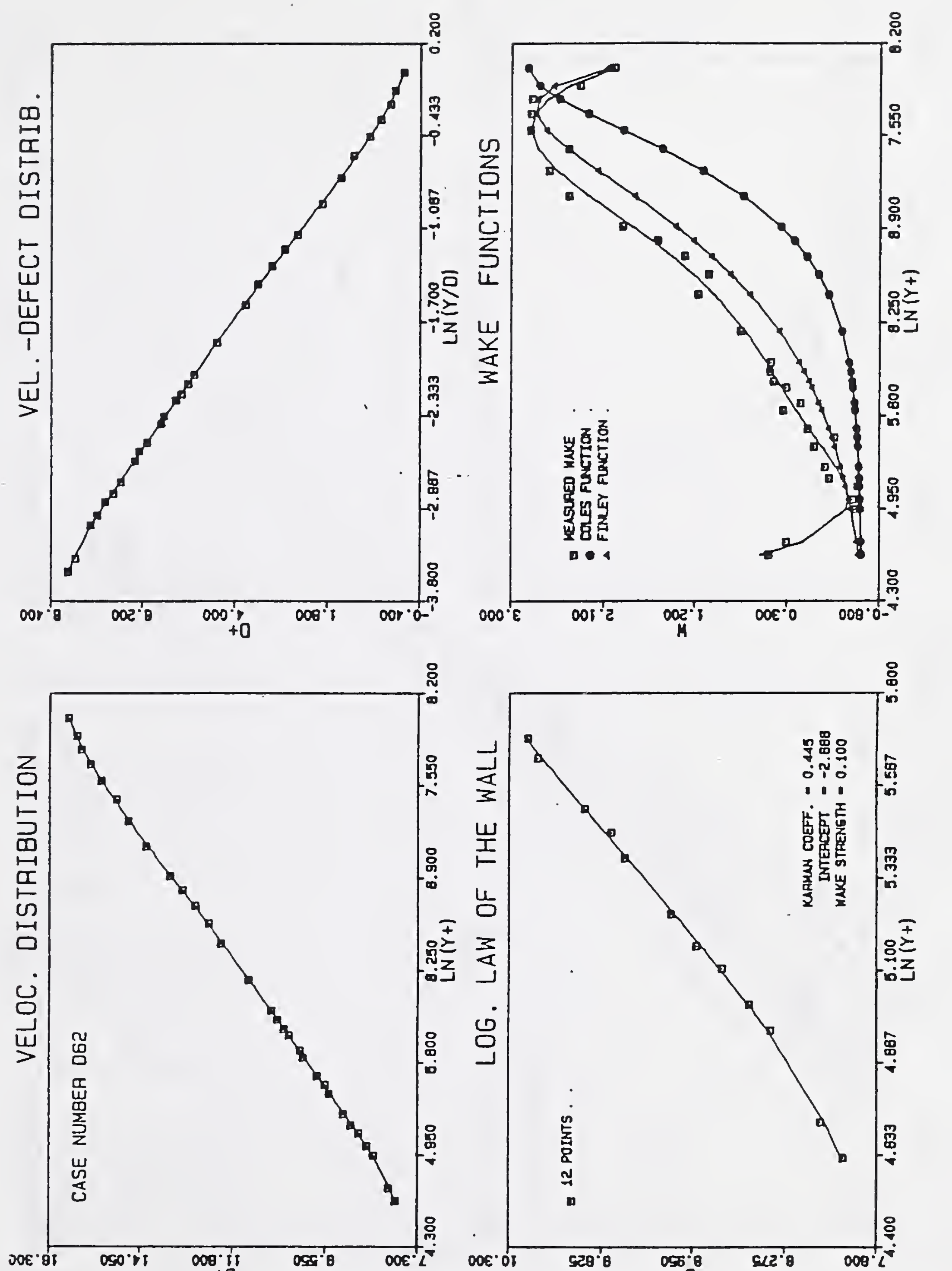


Figure 3.77: Distributions assuming null virtual origin. Case number 62.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

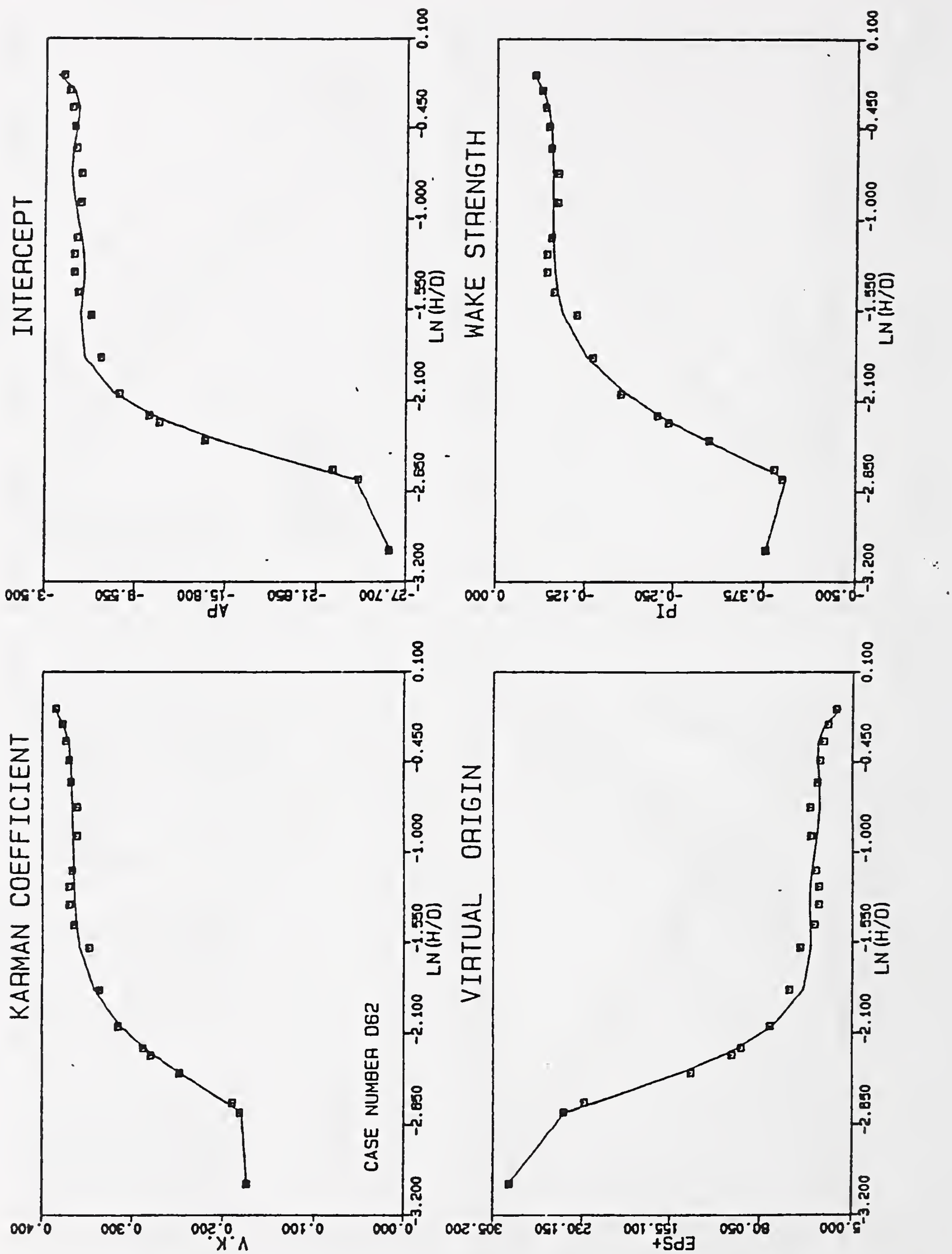


Figure 3.78: Parameter variation with the virtual-origin-search thickness H. Case number 62. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

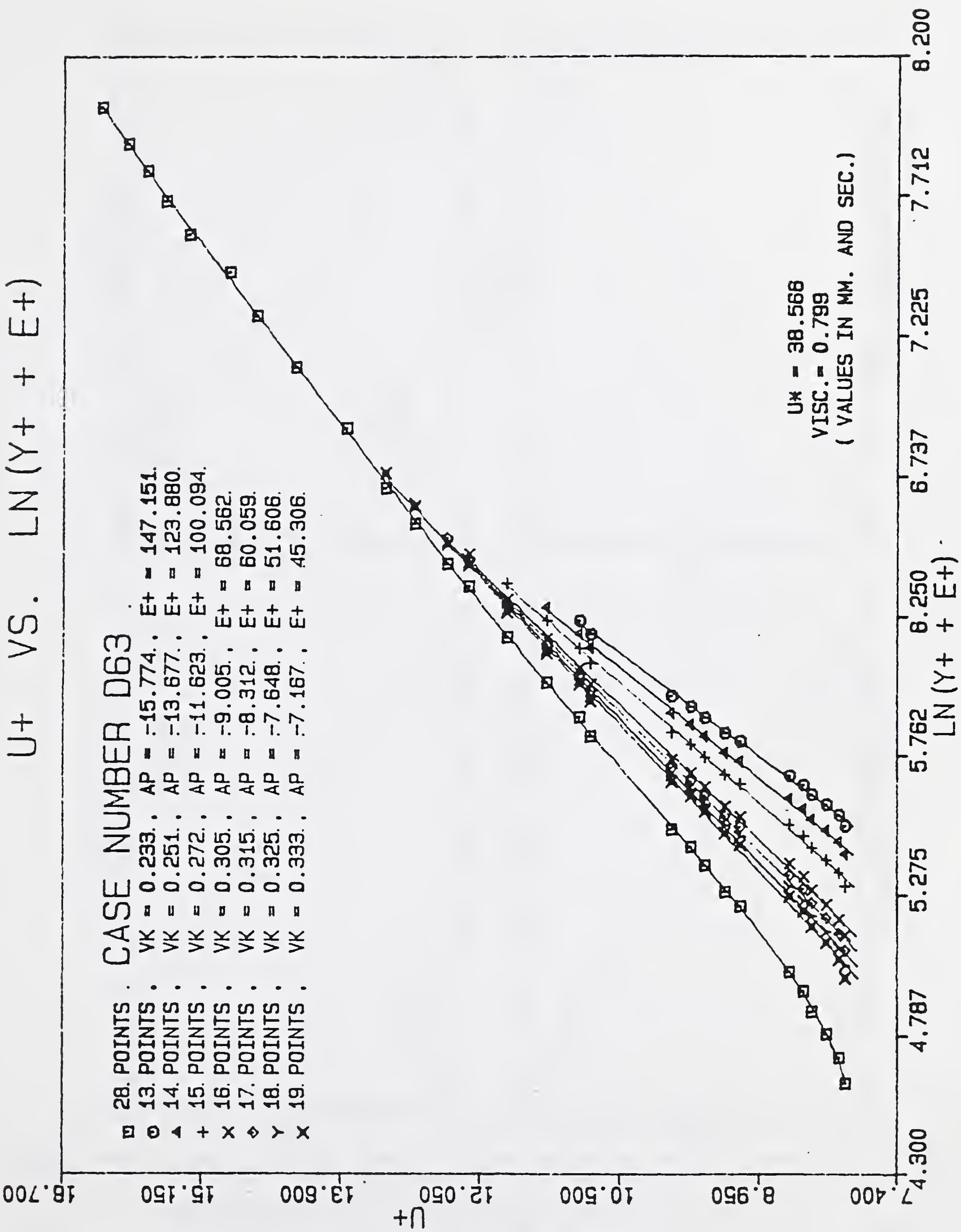


Figure 3.79 : Virtual-origin search. Case number 63.

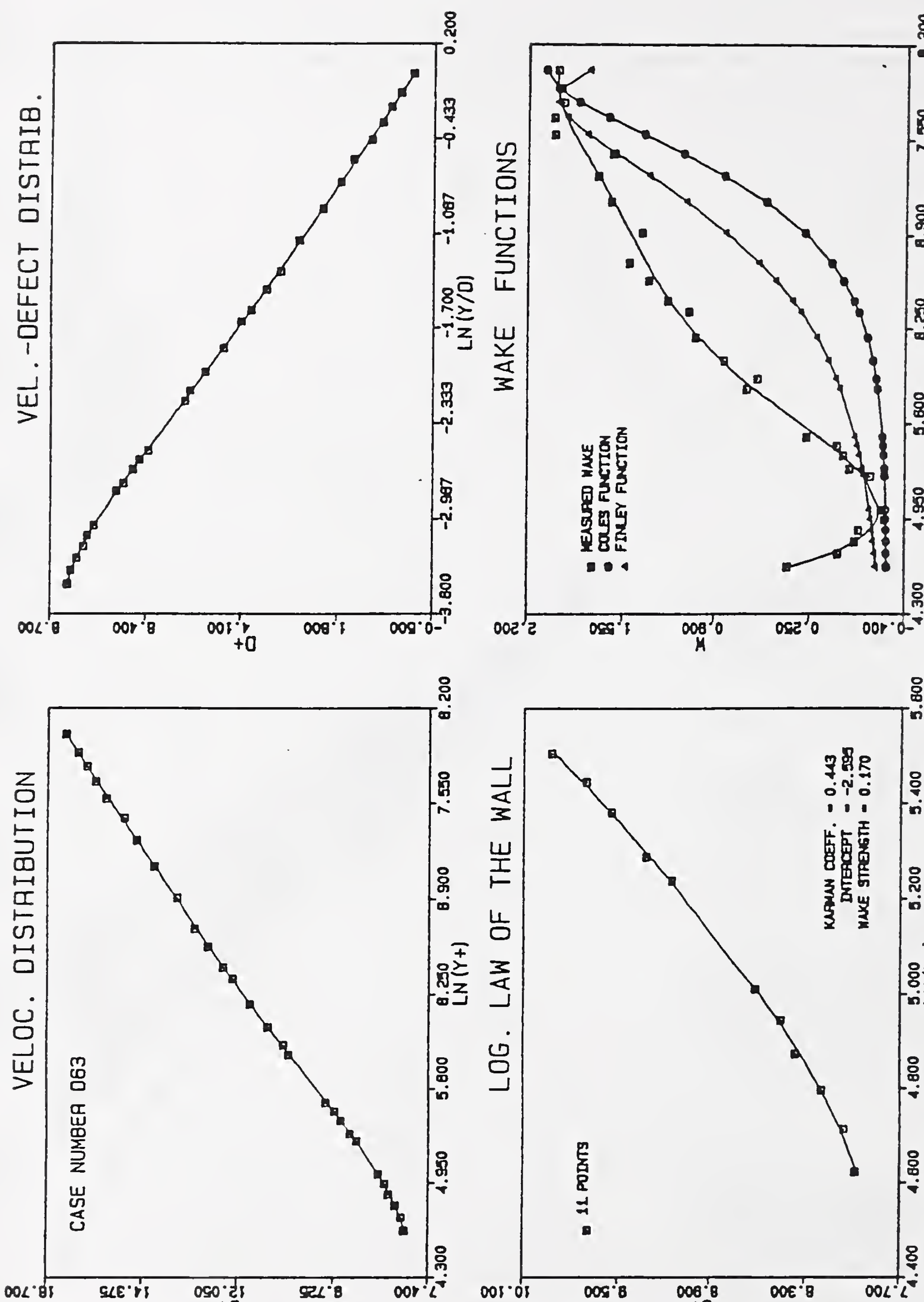


Figure 3.80: Distributions assuming null virtual origin. Case number 63.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

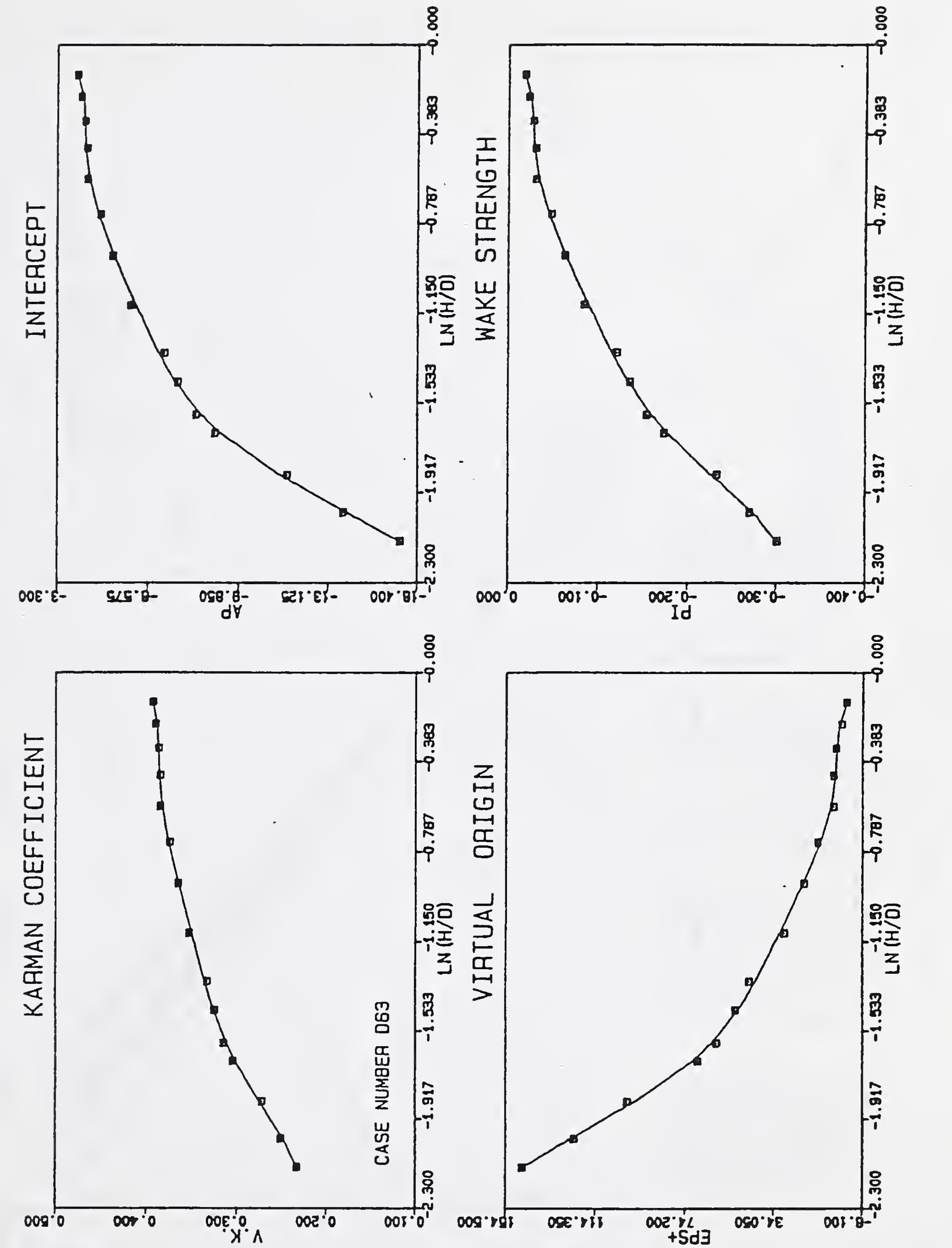


Figure 3.81: Parameter variation with the virtual-origin-search thickness H. Case number 63. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

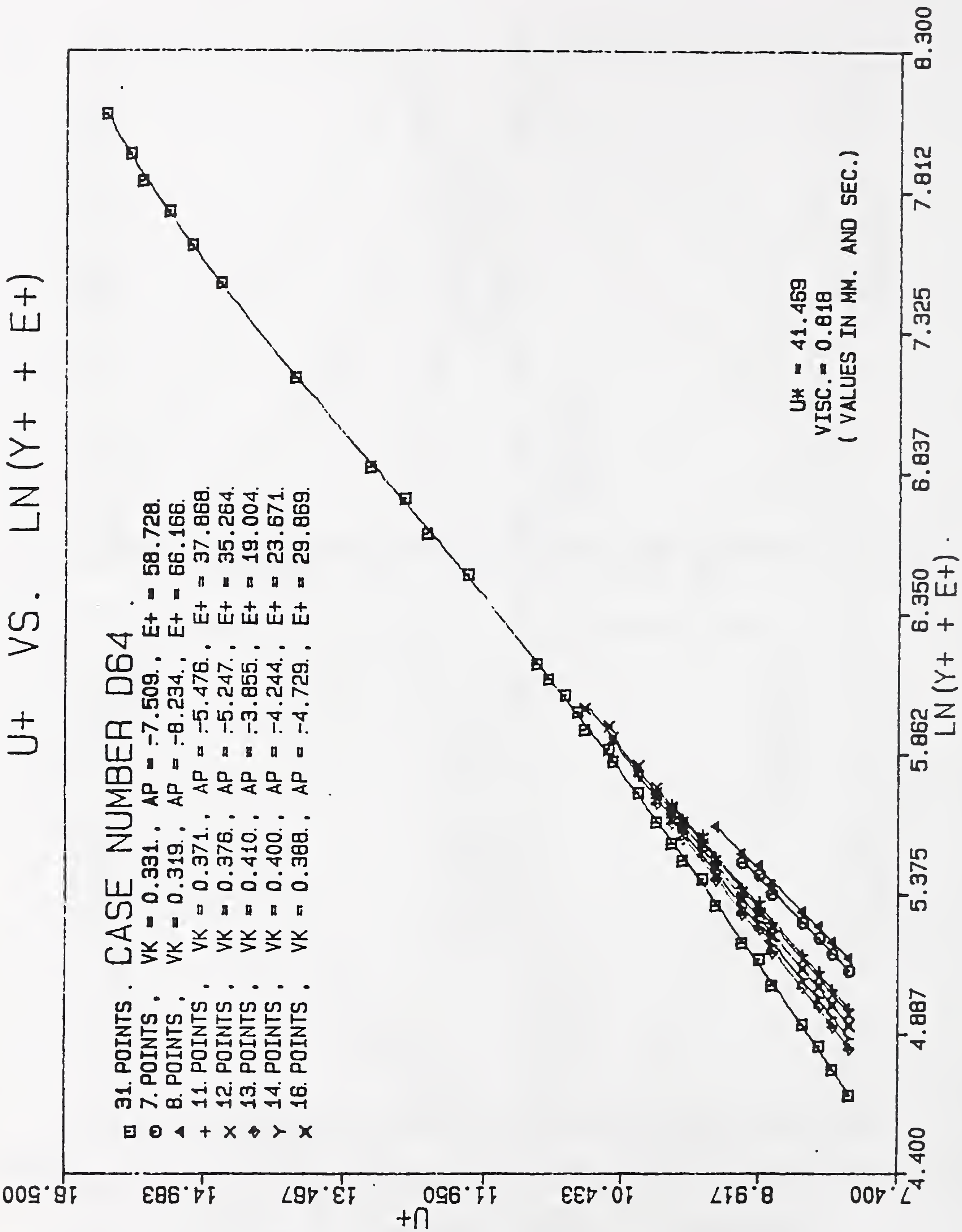


Figure 3.82 : Virtual-origin search. Case number 64.

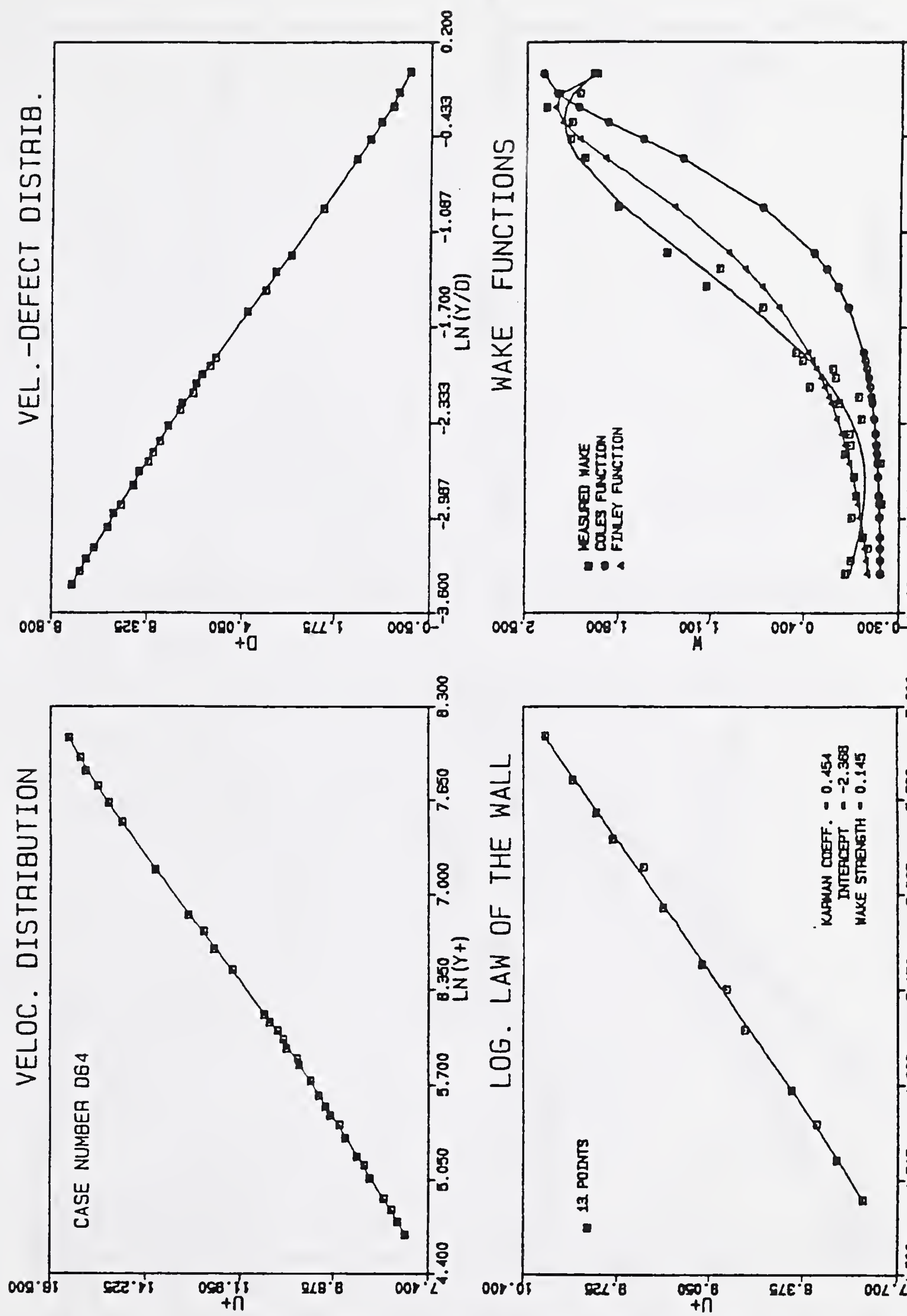


Figure 3.83: Distributions assuming null virtual origin. Case number 64.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

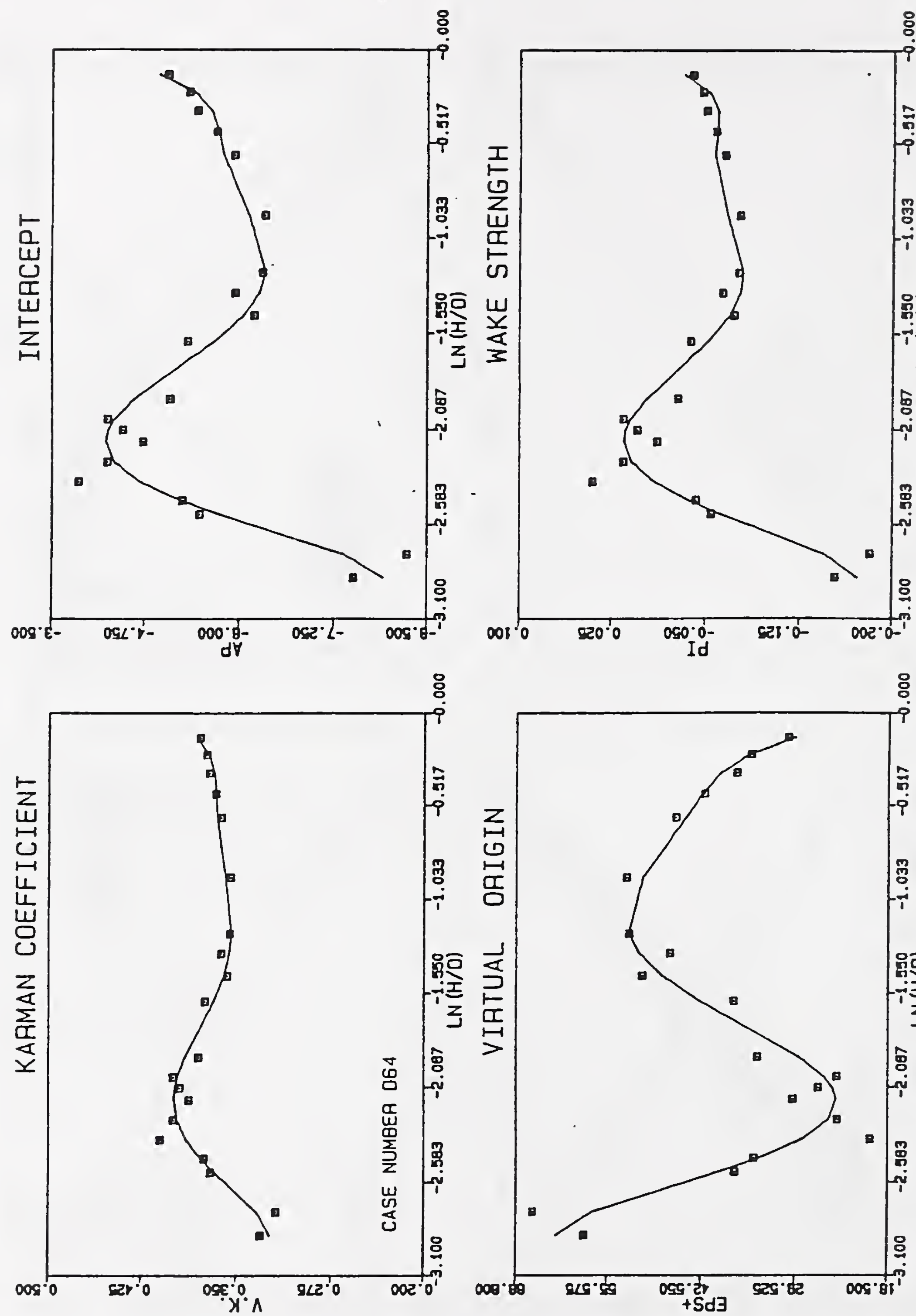


Figure 3.84: Parameter variation with the virtual-origin-search thickness H. Case number 64. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

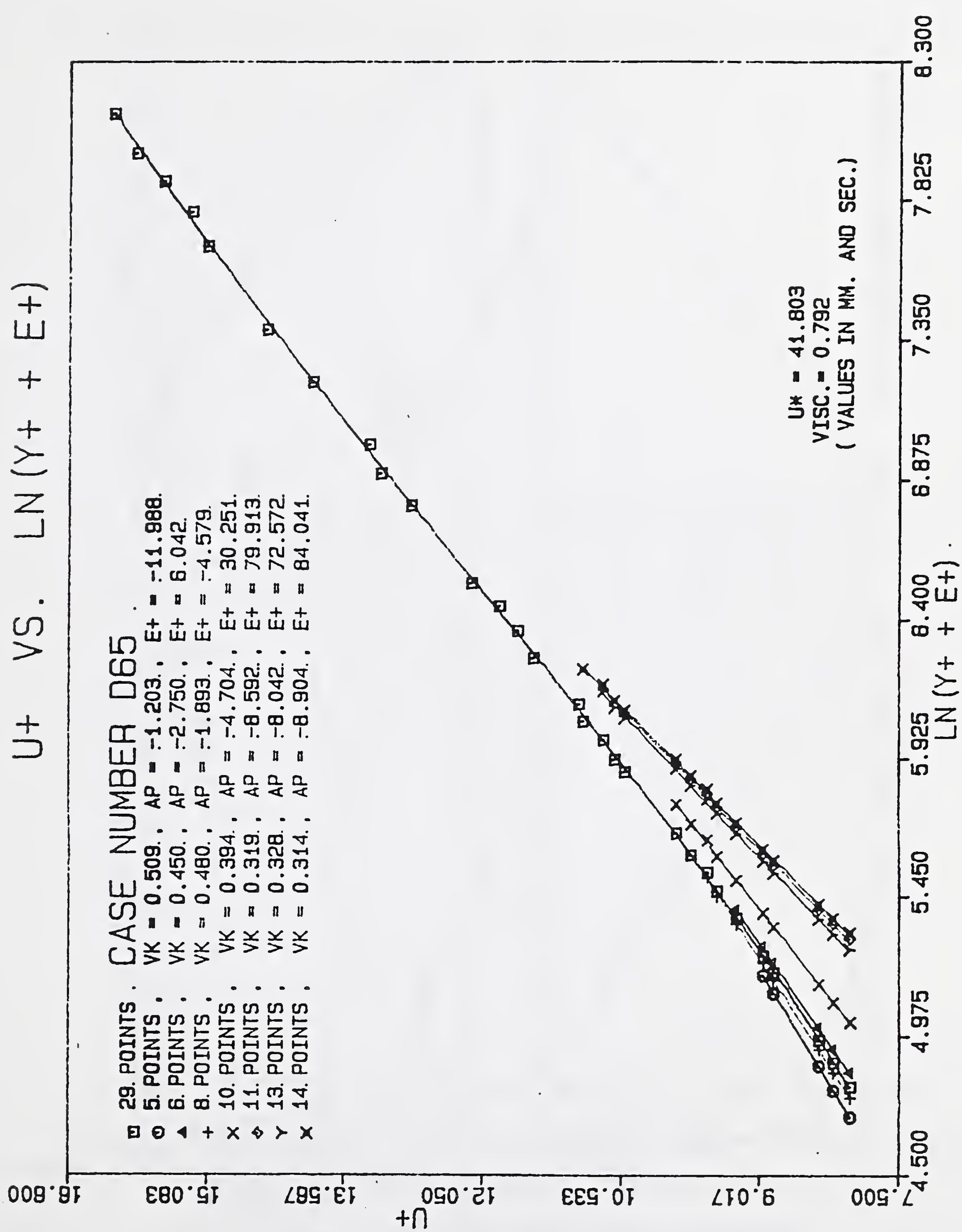


Figure 3.85 : Virtual-origin search. Case number 65.

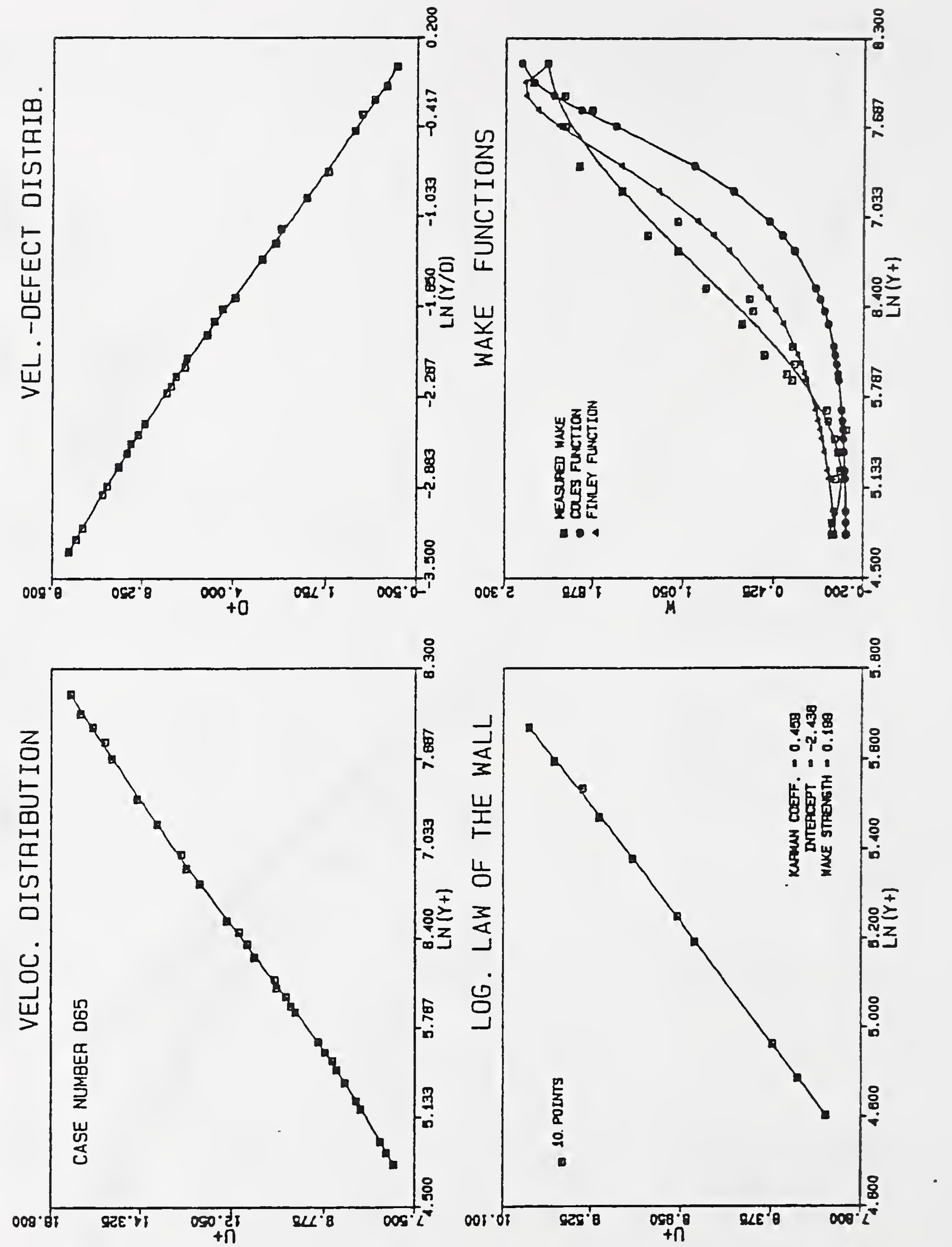


Figure 3.86: Distributions assuming null virtual origin. Case number 65.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

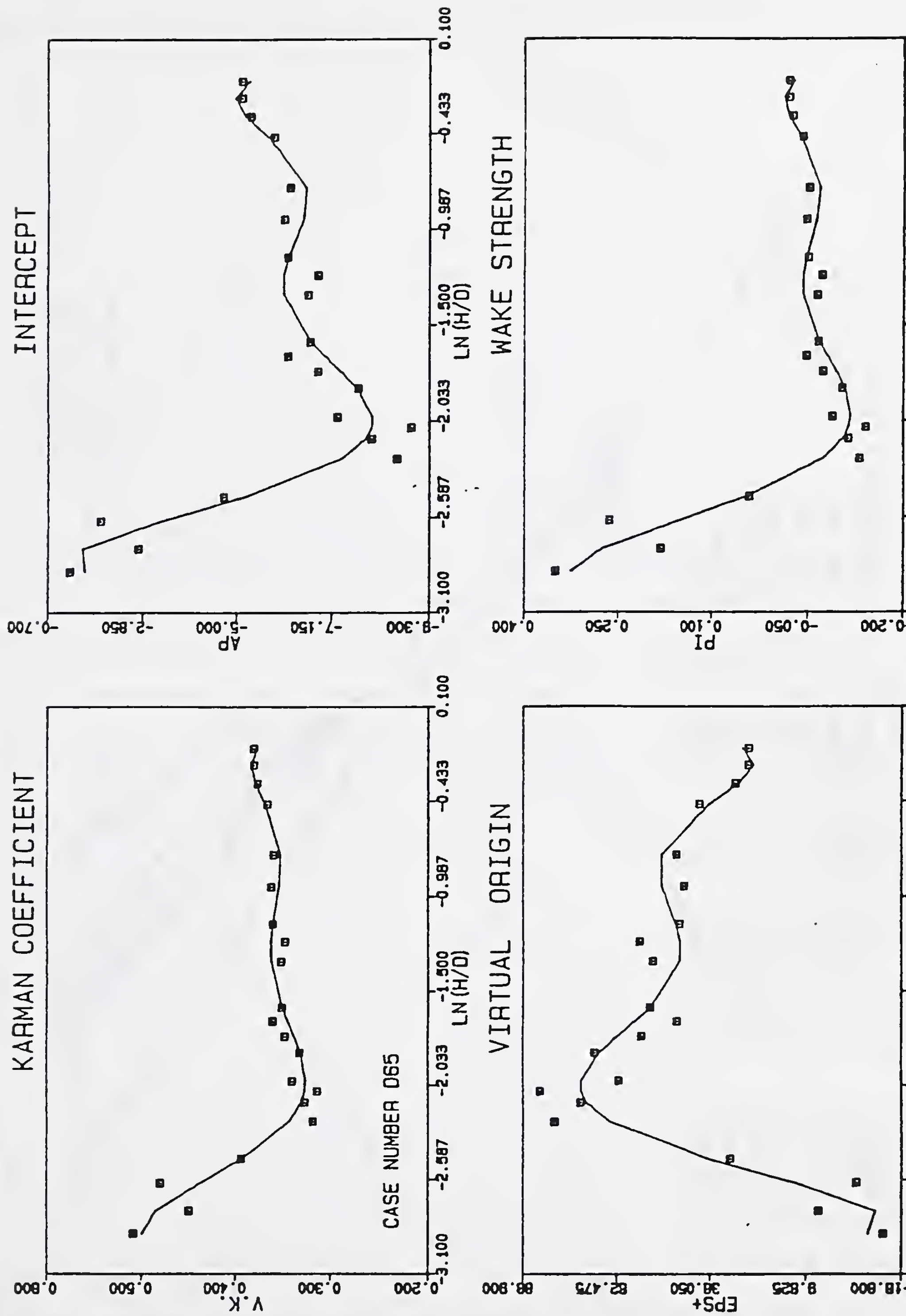


Figure 3.87: Parameter variation with the virtual-origin-search thickness H. Case number 65. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

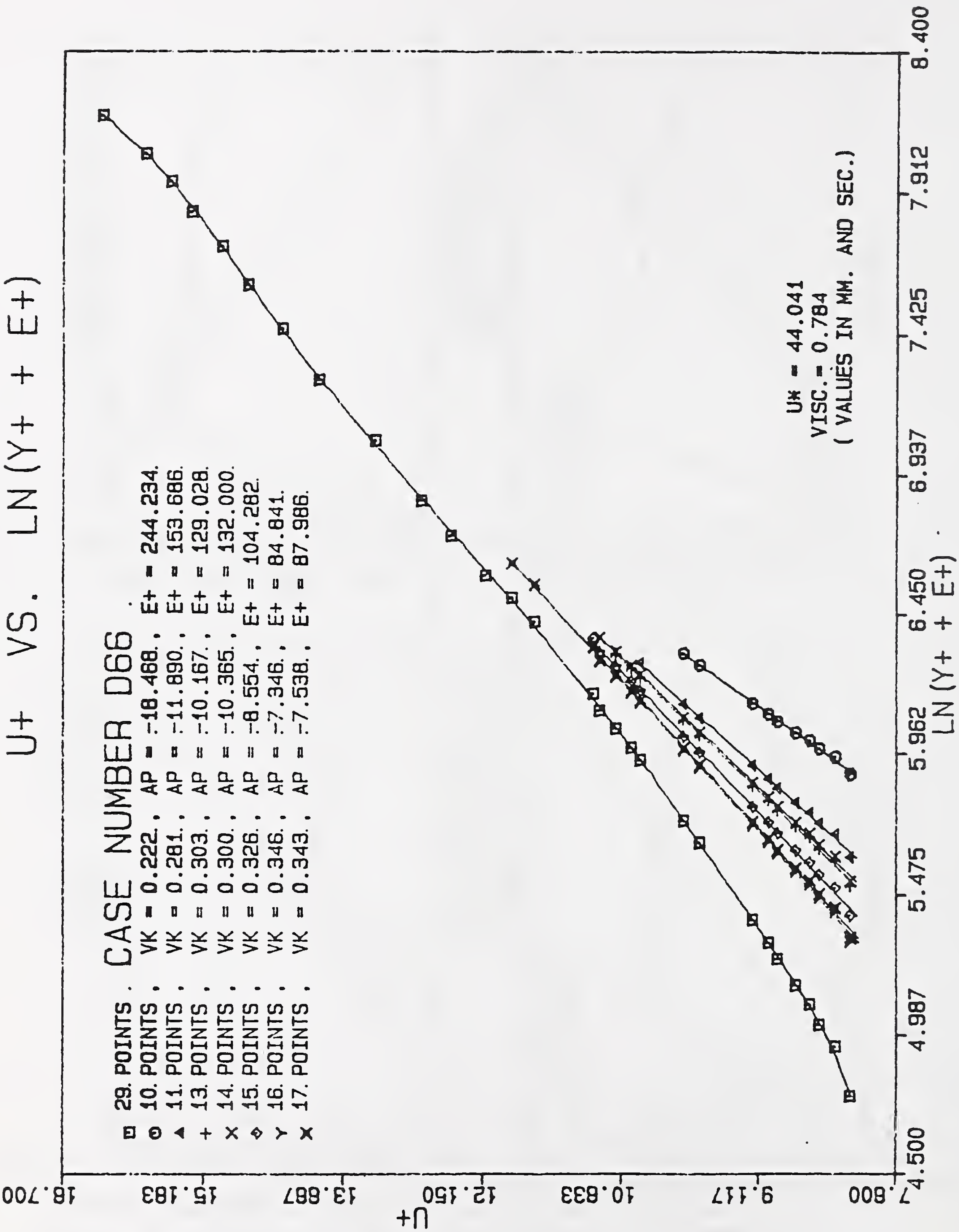


Figure 3.88 : Virtual-origin search. Case number 66.

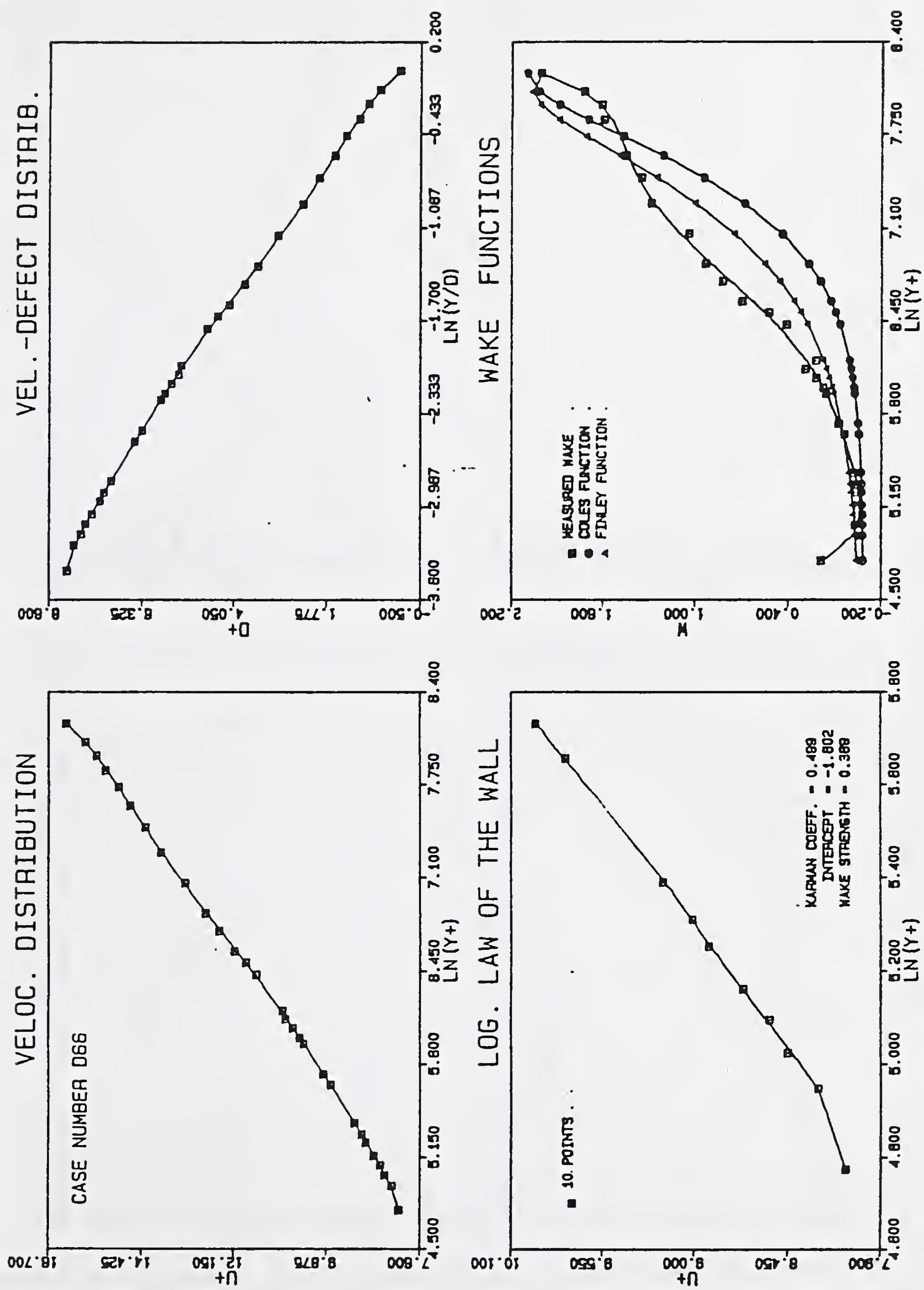


Figure 3.89: Distributions assuming null virtual origin. Case number 66.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

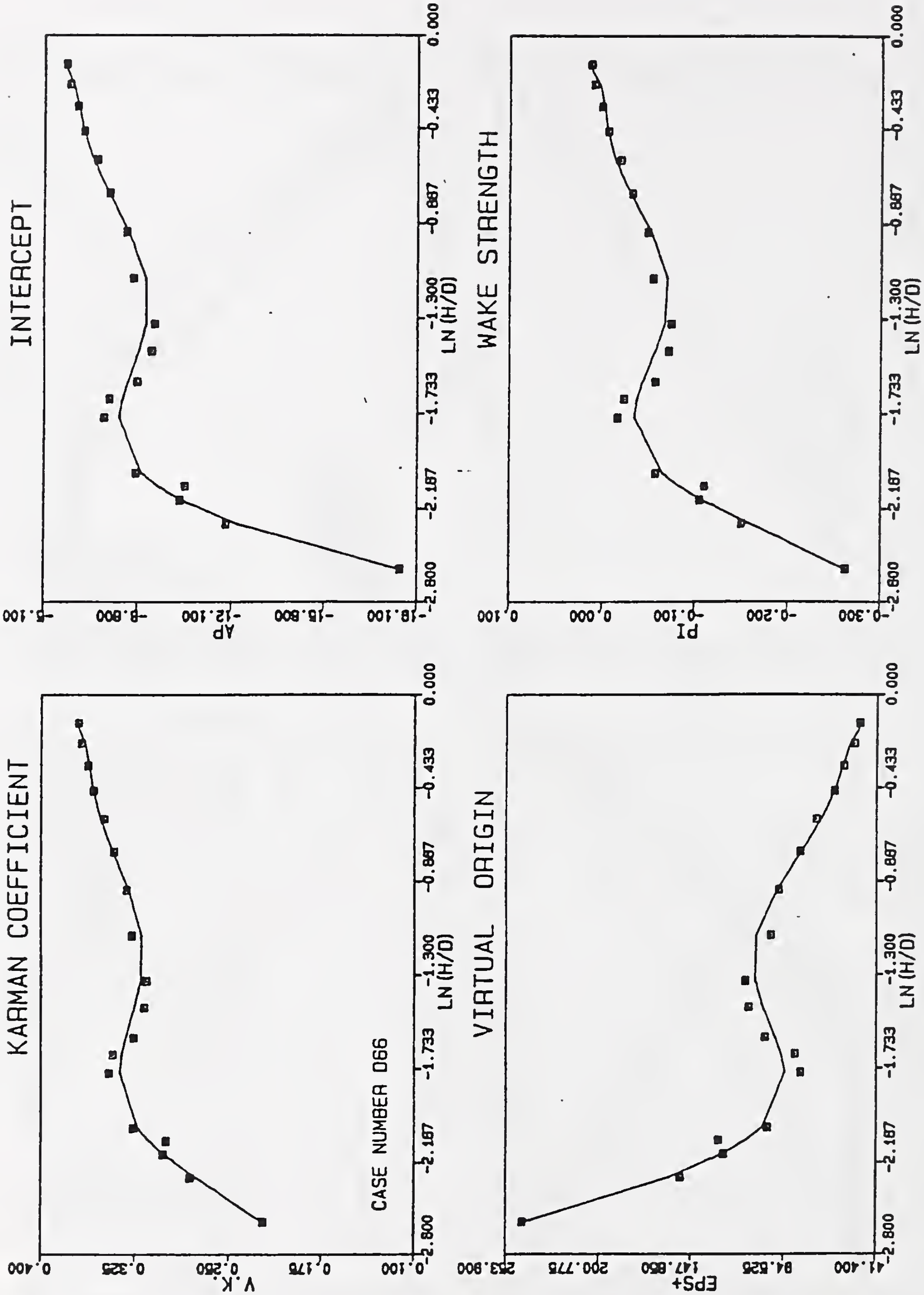


Figure 3.90: Parameter variation with the virtual-origin-search thickness H. Case number 66. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

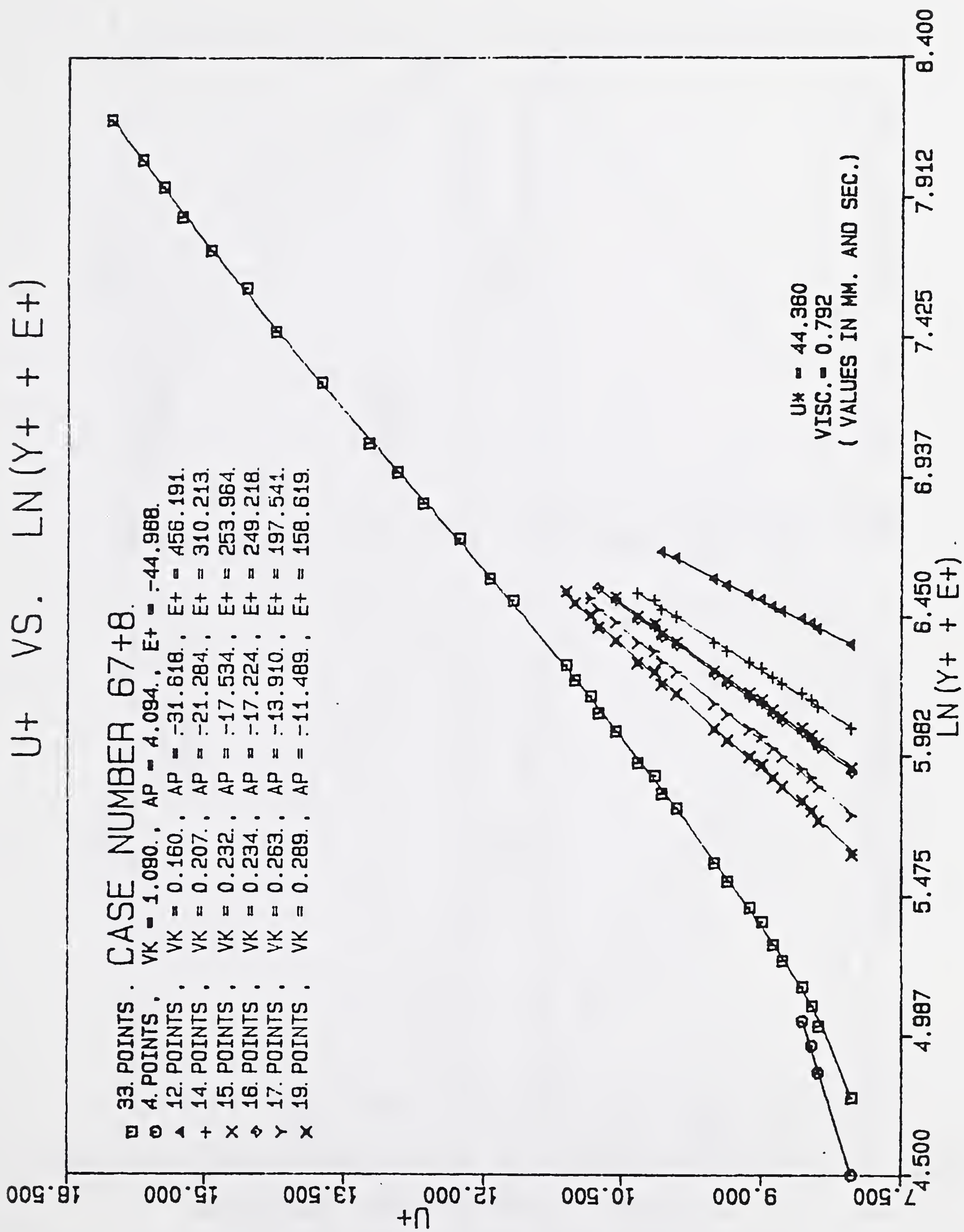


Figure 3.91 : Virtual-origin search. Case number 67+8.

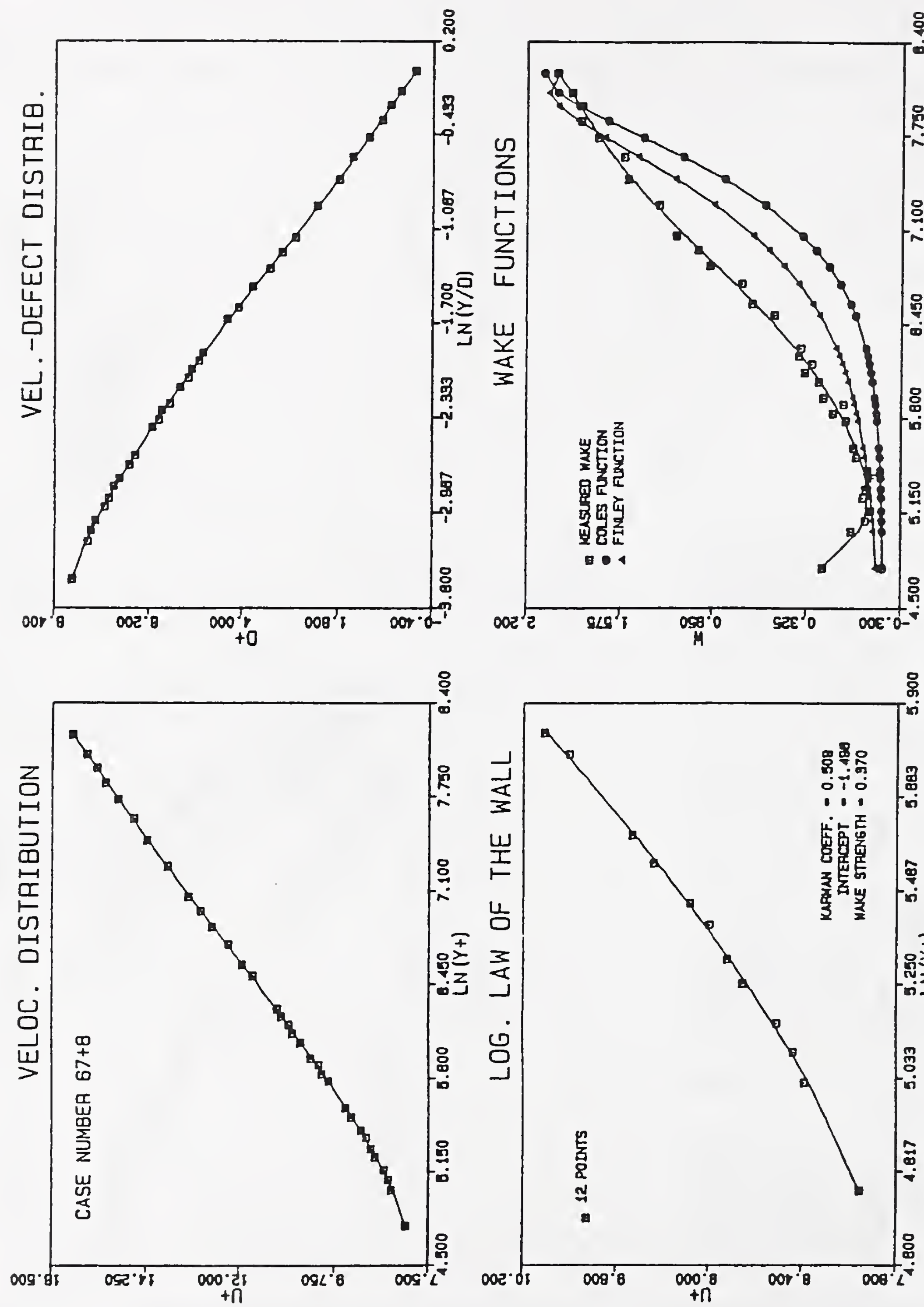


Figure 3.92: Distributions assuming null virtual origin. Case number 67+8.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

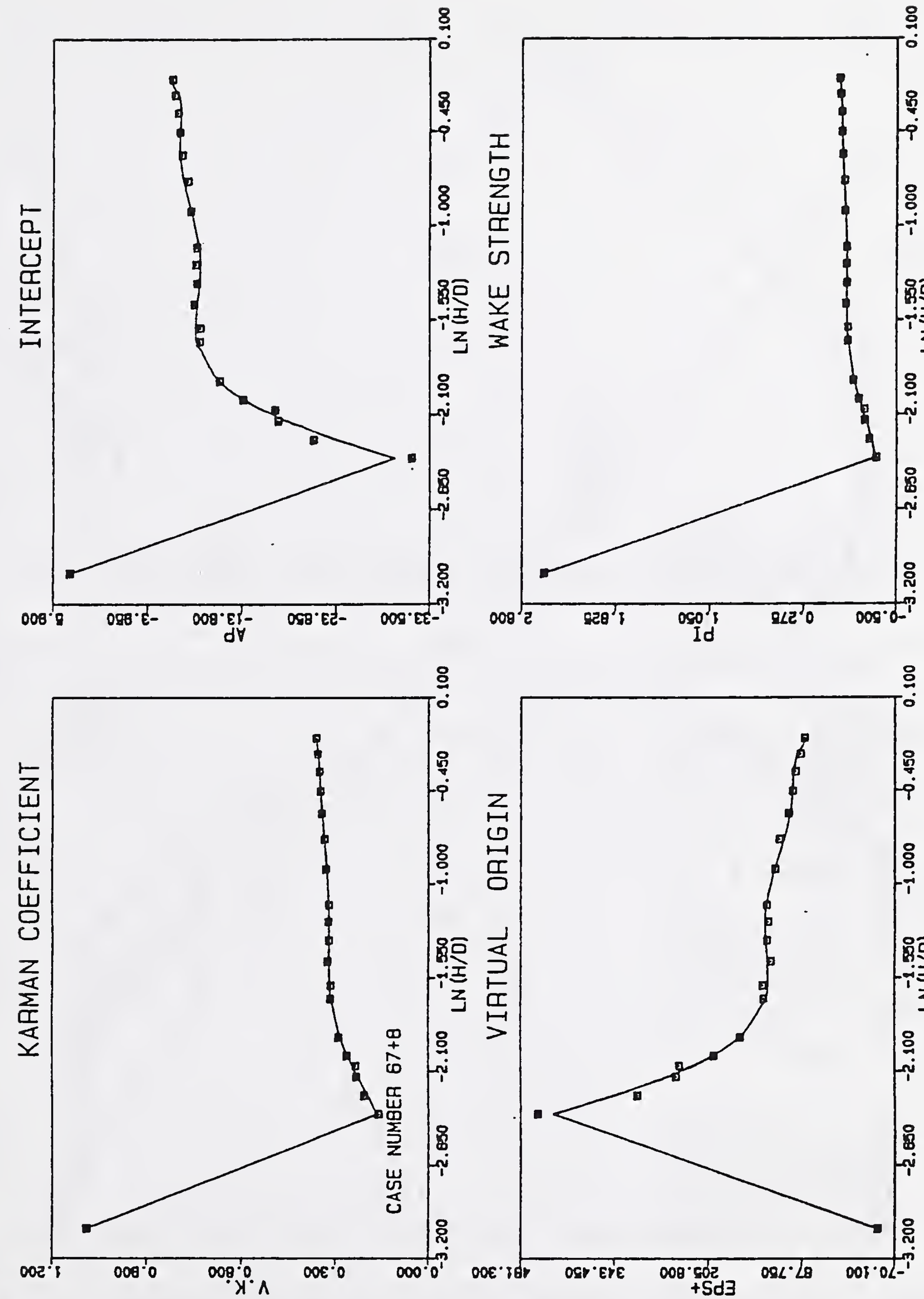


Figure 3.93: Parameter variation with the virtual-origin-search thickness H. Case number 67+8. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

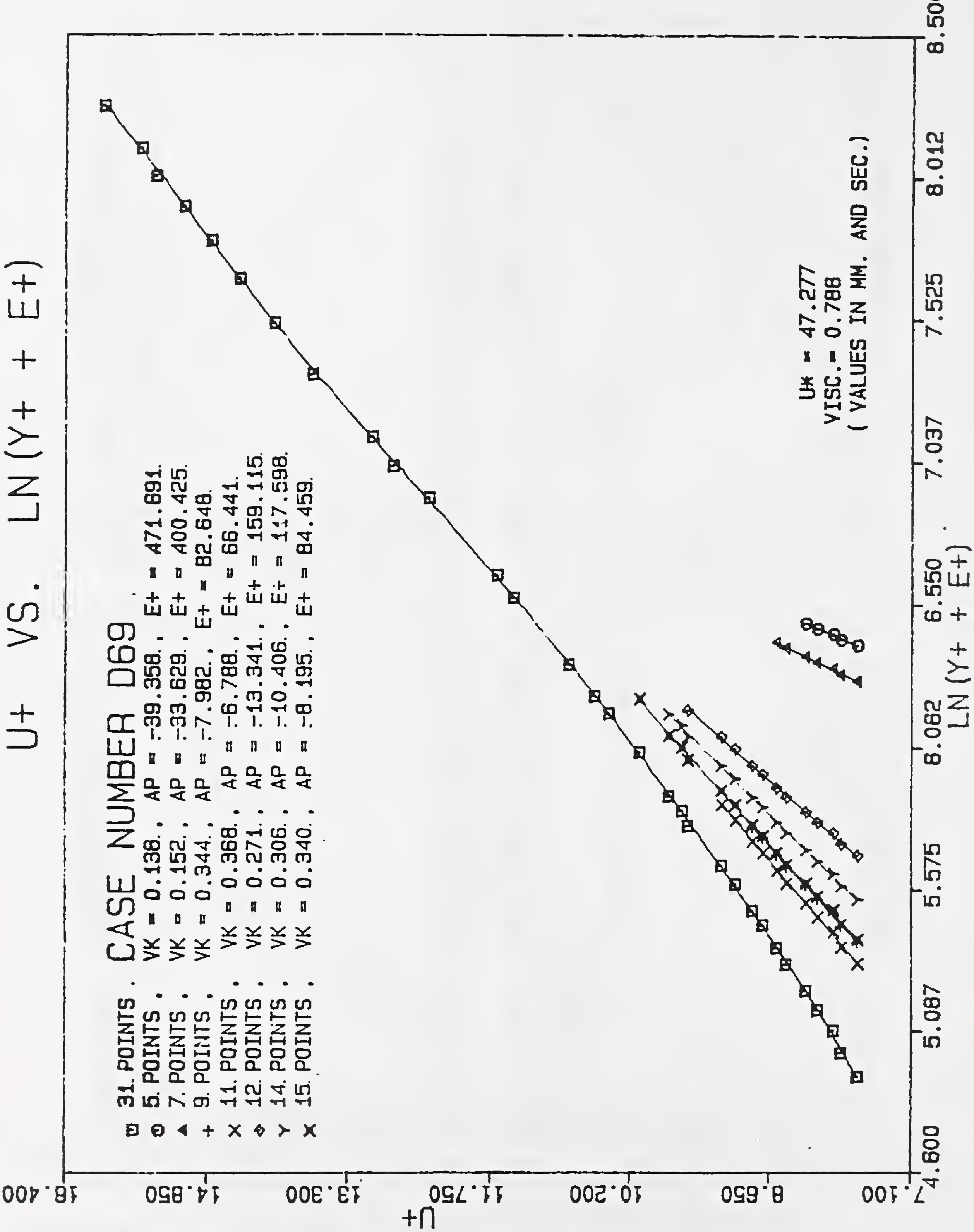


Figure 3.94 : Virtual-origin search. Case number 69.

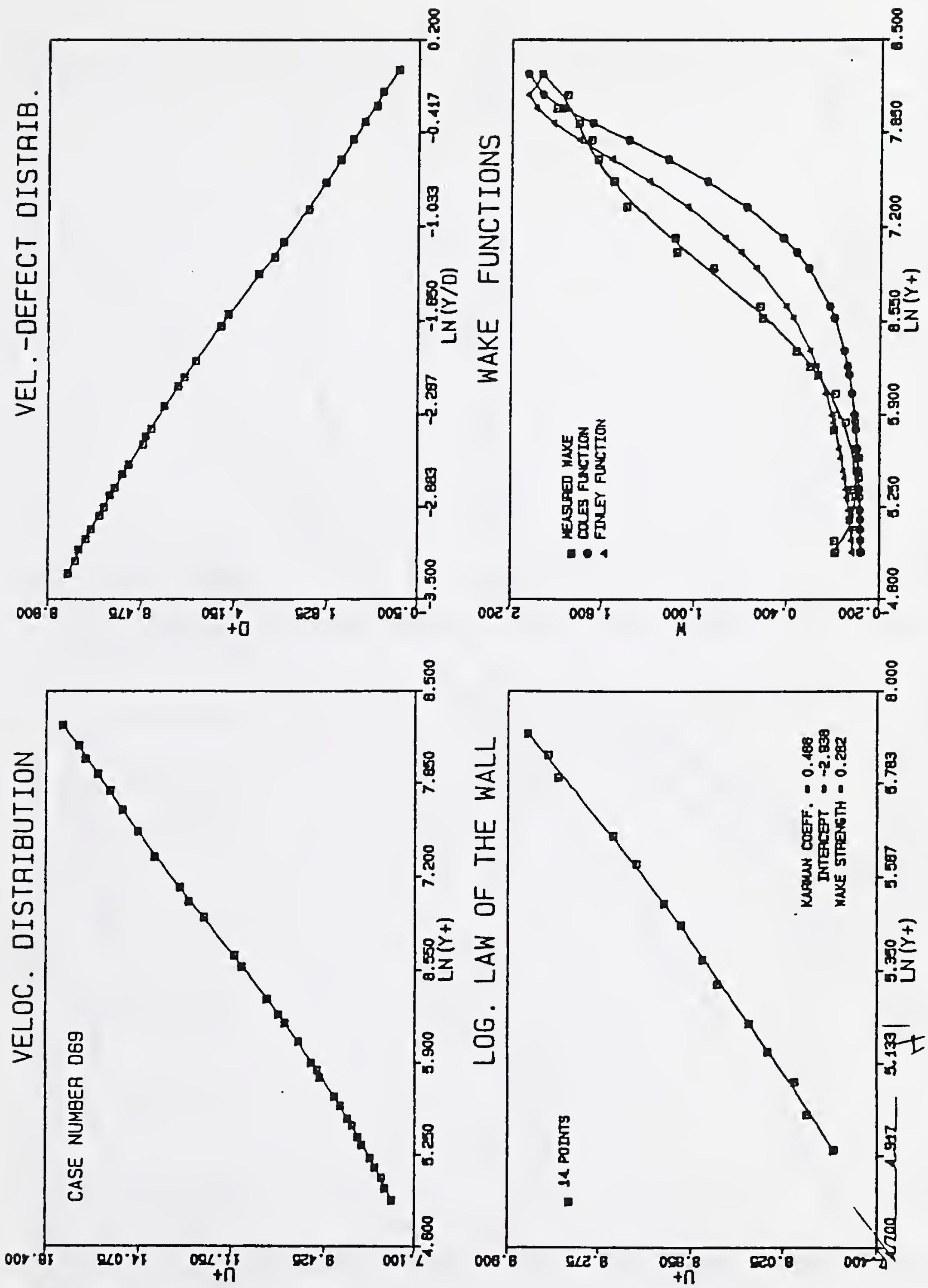


Figure 3.95: Distributions assuming null virtual origin. Case number 69.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

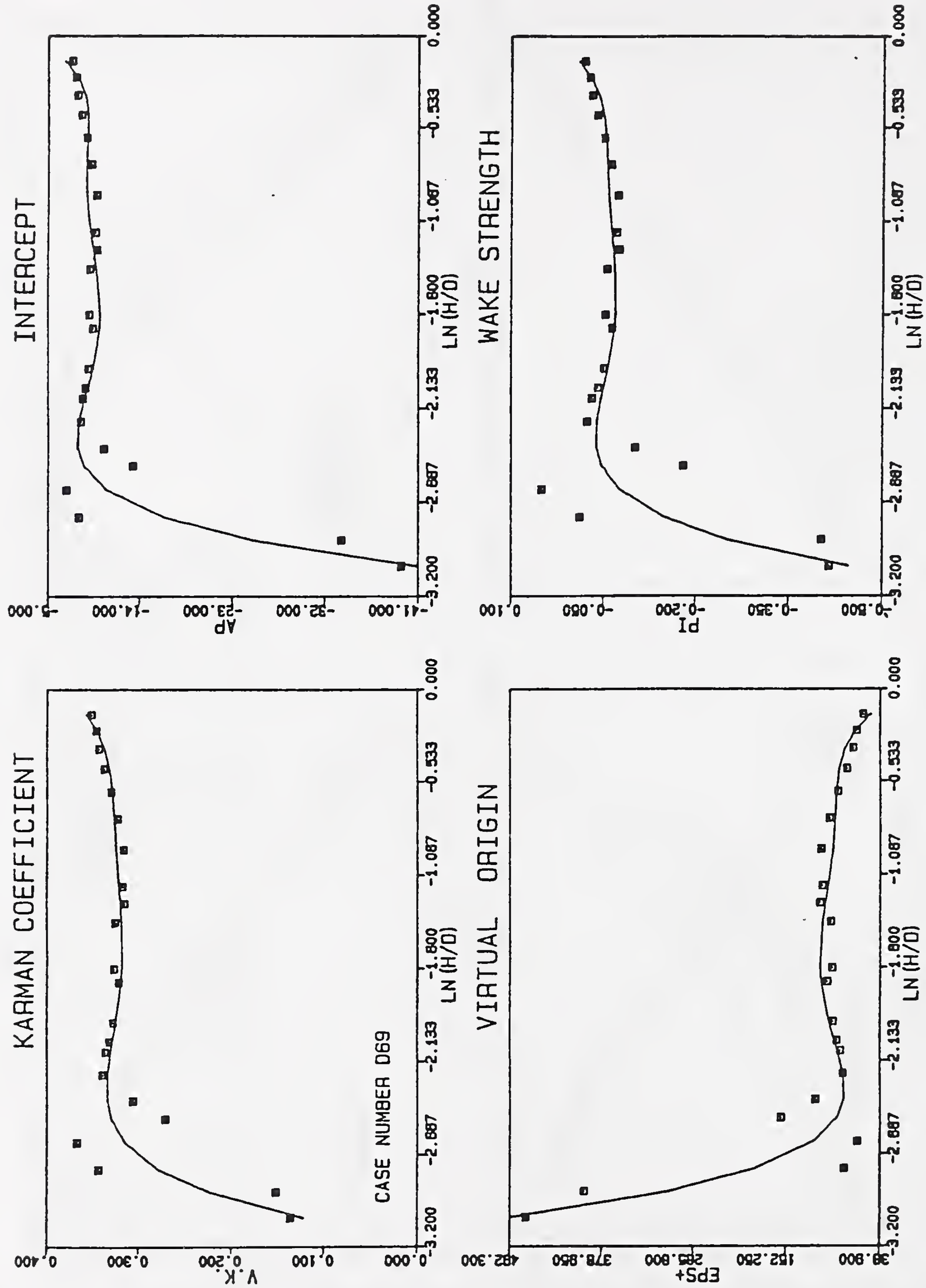


Figure 3.96: Parameter variation with the virtual-origin-search thickness H. Case number 69. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

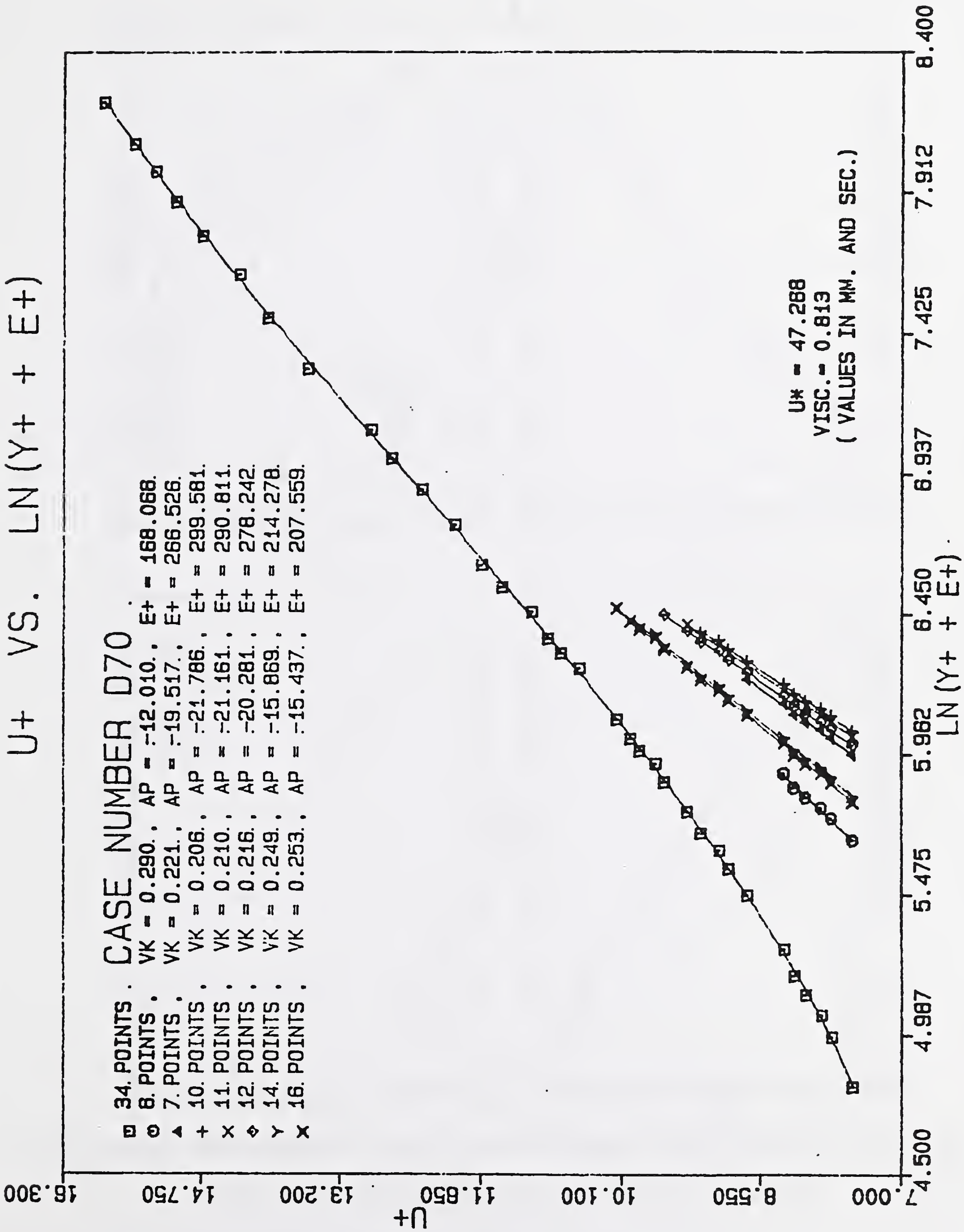


Figure 3.97 : Virtual-origin search. Case number 70.

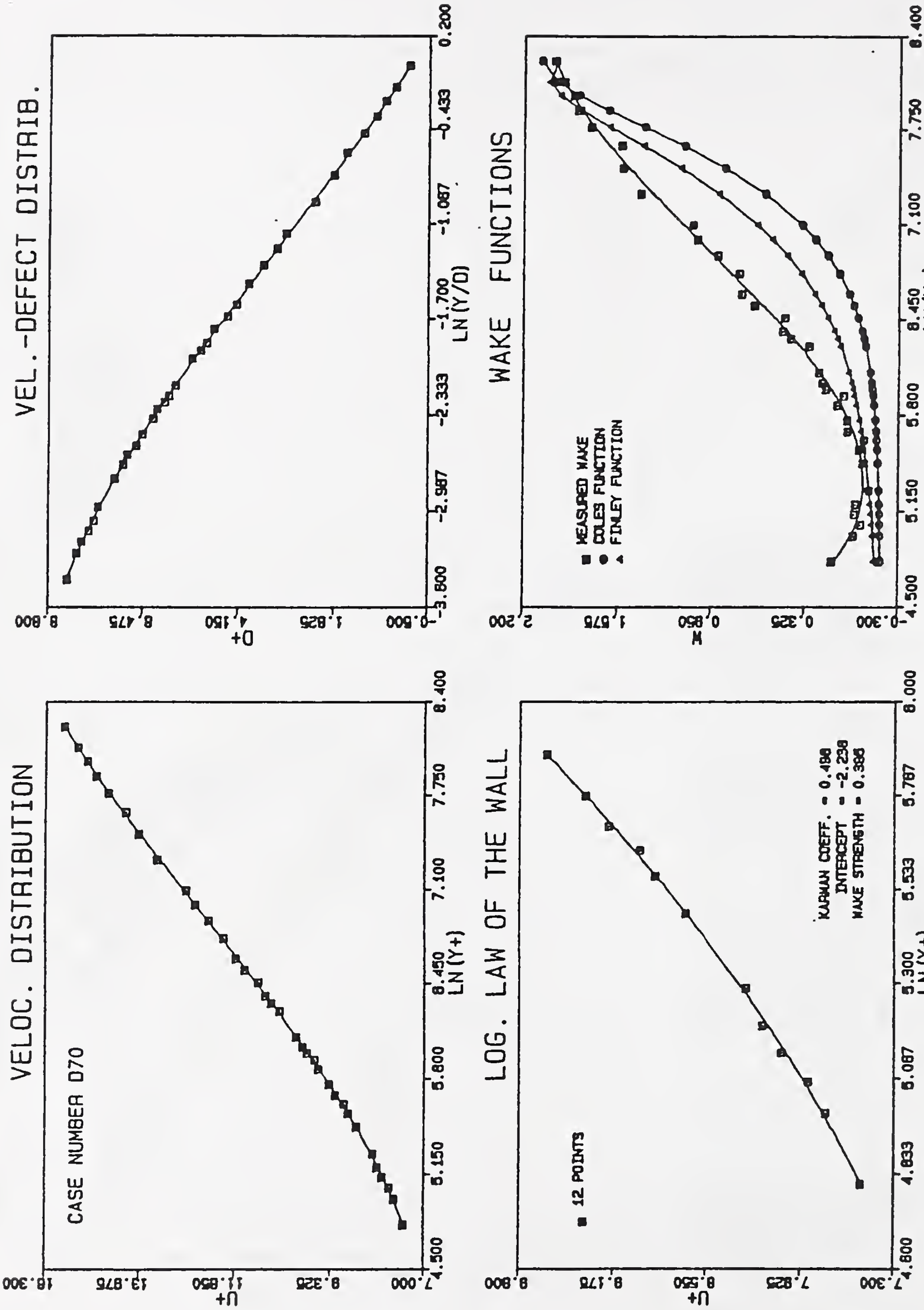


Figure 3.98: Distributions assuming null virtual origin. Case number 70.

a) Velocity Profile, b) Velocity-Defect distribution

c) Logarithmic law of the wall, d) Wake functions.

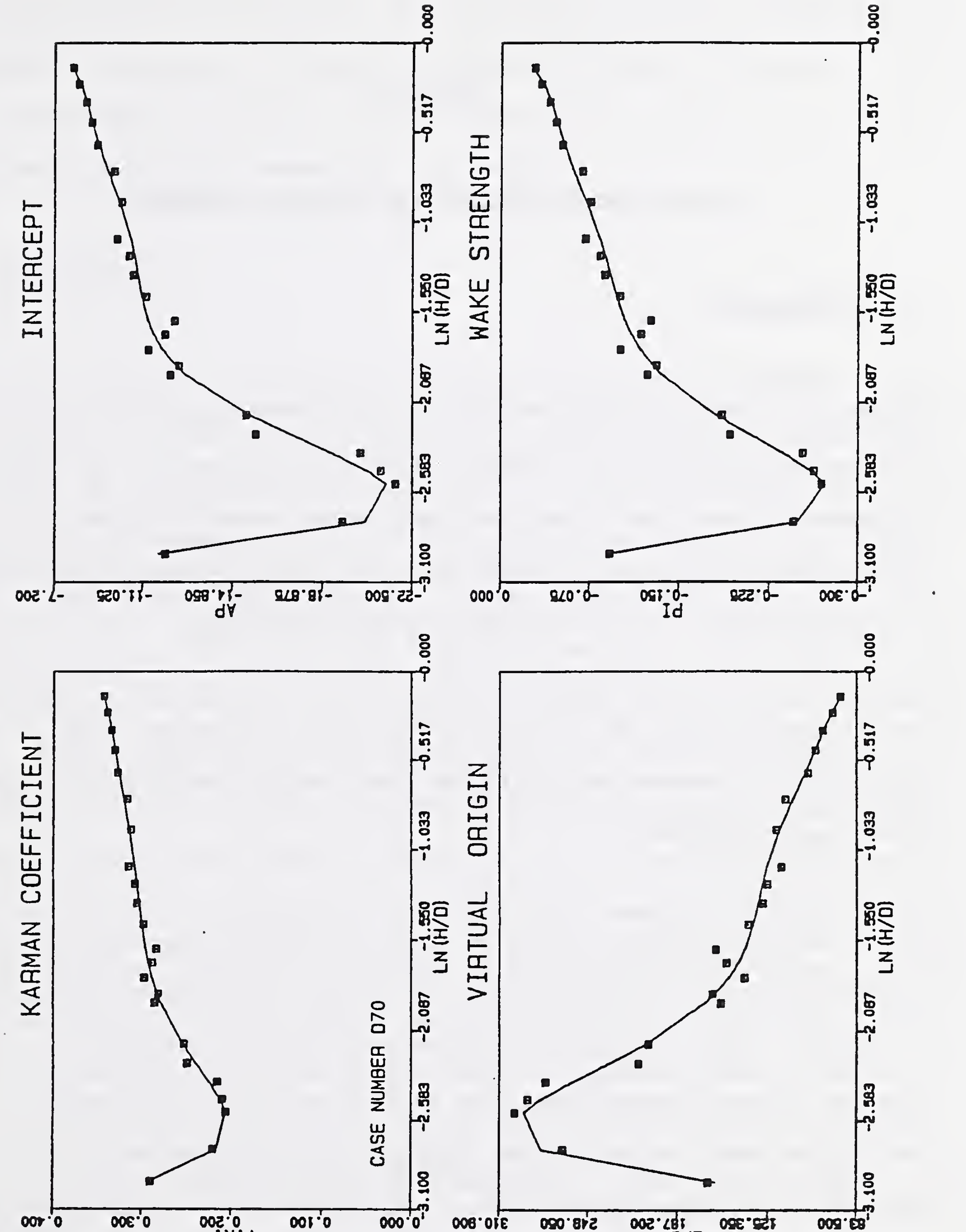


Figure 3.99: Parameter variation with the virtual-origin-search thickness H. Case number 70. a) Karman coefficient, b) Intercept, c) Virtual origin, d) Wake strength.

CHAPTER 4

DESCRIPTION OF THE PROGRAM "VELMEAS" DEVELOPED

4.1. Introduction

The program VELMEAS (VELocity MEASurements) has been prepared for the purpose of collecting and analysing samples produced in voltage form by means of an instrument of any kind. That instrument might commonly consist of a Pitot tube connected to a pressure transducer, a hot film anemometer probe attached to a proper device, or a laser-doppler anemometer system.

The program can also be used to collect and analyse any kind of random signals and be expanded with relative ease, because the tasks are separated in Main- and Sub-Menus.

In its present version, data from only one channel can be collected and analysed at a time. An extension of the program for use with a large number of channels under simultaneous operation has been contemplated in the structure of the program however, to facilitate further developments. Since the program makes extensive use of graphics and regression analysis, the routines that perform these tasks were written in the most general fashion, forming a good base for future enhancements.

The program has been written in conversational fashion, with the user

selecting tasks during execution. The source code, written in FORTRAN IV and reproduced in Appendix A, contains a profusion of comment cards which, along with this Chapter and the User Manual (Chapter 5), would facilitate future developments that other researchers may require.

4.2. Portability

To test portability, the program has been installed in two different machine environments. It was first implemented at the USDA National Sedimentation Laboratory on a MODCOMP Classic computer and attached Hewlett-Packard 7220 plotter and analog-to-digital converter. There the program was compiled in MODCOMP FORTRAN IV language and the plotting library used was the Hewlett-Packard HP-ISSP. Then the program was implemented at The University of Mississippi on an AMDAHL V-8/470 computer running an IBM CP/CMS operating system (thus compatible to IBM mainframes) an attached Tektronix 4612 hardcopier, a Tektronix 4662 multi-pen plotter, and a Versatec (Hardcopier) plotter. Graphics perfomance was also tested in a Tektronix 4112-A Graphic terminal. In this implementation the program was compiled in IBM VS FORTRAN and the plotting library used was the Calcomp Model #763 software. When using the Tektronix terminal, it is necessary to use routines which are part of the Terminal Control System of the Tektronix Graphics Package, and commands specific to each terminal. For both Tektronix and Versatec plotters, execution files written in CMS are necessary. They are listed in the Appendix B.

A few instructions differ in both versions but are clearly identified in the program by comment cards beginning with "C:::::". Since no analog-to-digital

converter was available in the AMDAHL environment, the corresponding version does not contain the data adquisition ANLOGO subroutine. Apart from these minor differences, the analysis was made on both computers using all aforementioned graphic devices without difficulty. This establishes the general portability of the program.

4.3. The Main Program

The Main program manages the subroutines, but also does some tasks, including Menu operations and transformations of voltage to velocities (or other physical variables) through an appropiate formula. It also prepares a table on File number 14 (FN14) where all statistical variables are stored for further analysis. That table can grow through successive runnings of the program because new values are added to the end of the table for different probe positions. An option allows erasing previous records. This is useful while checking the state of the experiment in progress because definitive readings can be recorded on cleared files. Other options available are explained further in Chapter 5 (User Manual). The program operates in conversational fashion using an input file KI5 and an output file KO3 (number 5 and 3 in MODCOMP version and number 6 and 6 in IBM version, respectively), both defined for the terminal device and subsequently jointly referred as the terminal screen. They are used not only in the Main program but in subroutines, as required by the procedure. Frequently, the output is simultaneously sent to the file number 12 (FN12) for documentation and further analysis. This file FN12 is used elsewhere in the program to record results of the analysis in tabulated form. Hence it contains a story of the entire procedure.

The Main program also clears or optionally protects from clearing the files FN12 and FN14. It initializes (when new) the file FN14. It calls the appropiate analysis mode and/or data collecting through the appropiate options contained in a "Main Menu" (See 5.2).

4.4. **Data Acquisition**

Random signals are obtained from an analog voltage output and transmitted by an analog-to-digital converter. The task is performed by subroutine ANLOGO. This subroutine was previously available as a separate data acquisition program at the USDA Sedimentation Laboratory but has been slightly modified for this program. In this version it computes the minimum and maximum values (in Volts) found through the collecting process, which are needed for other subroutines. The cited subroutine is machine-dependent and contains some parts written in assembler language. No large array is necessary, for values are taken in packs of 32 and immediately stored in file number 2 (FN2) defined on a peripherial device (commonly a hard disc and eventually a tape). Other parts of the program act in a similar way, reading and computing the original data in packs of 32. ANLOGO also uses the File Number 1 (FN1) as required by the analogic-digital converter. FN2 will contain all the voltages (samples) read at the last probe positioning. A new sampling will erase the values recorded in the previous one. This avoid the generation of an excessively large file, since many positions may be sampled in a single application, each position requiring tens of thousands of samples. Before collecting data in a new position, the statistical analysis is made, thus eliminating the need of further recording of the original values.

4.5. Statistical Analyses

Subroutine STATI1, called by the Main program, makes basic statistic analyses and helps establish the readiness of the system for measurements. It computes the Mean and the Standard Deviation, and obtains the Probability Distribution of Frequencies (PDF) of the original signals sampled or of their converted (in the MAIN program) values. It also displays on the terminal screen these values and their PDF and writes this information in FN12. This is done in text mode to allow the use of non-graphic terminals, since the PDF permits the detection of oscillations, instabilities and other perturbations. Hence many operating characteristics of the flume or other physical environment under research can be checked on the terminal screen before the actual data acquisition begins. The readiness of the system for the measurements can in this way be verified.

For instance, when dealing with open channel flows, a positive skewness should be expected, according to experience, with a velocity measuring probe close to the channel bottom, and in any case only one peak should be present in the diagram. The signal PDF diagram is automatically scaled (and the scale indicated) in such a way to occupy the whole screen width of 80 columns to better show its features (See example in section 4.9). It also is normalized in such a way that its integral has the value one. Also, the normalized frequencies are tabulated against values (in Volts).

Subroutine STATI2 , called by the Main program, makes further statistical analysis. It uses the previously found PDF to compute the Mode, Skewness and Kurtosis. To accomplish this in the most objective, efficient and accurate

way, no fitting of theoretical distributions is done. Instead, the first to fourth moments about the zero are computed in a unique loop over the collected values. Then the moments about the mean are obtained as functions of the former about the zero, the Shepard corrections are introduced, and Beta and Gamma parameters computed (See example in section 4.9).

Finally Skewness and Kurtosis are computed as functions of the moments about the mean. The sign of the skewness is determined by the relative position of the median with reference to the mean instead of the mode, because this gives a more reliable determination of that sign, not being mostly influenced by local peaks as the mode is.

4.6 Regression Analyses

Function REGRE1, called by several subroutines obtains an N-order polynomial regression on M data points in X,Y arrays. The function name returns the standard error of estimate. The regression intercept and coefficients are returned as arguments. The procedure involves solving a system of equations with N unknowns, a task performed by Function SIMUL, which utilizes the Gauss-Jordan reduction method, including a maximum pivoting strategy. Values of the regression are subsequently obtained by systematically using the Function FREG1, which utilizes Horner's rule to optimize computational time. The codes for these three subroutines were taken with few modifications from the text of Carnahan et al (1969).

Subroutine BSTREG, called by several other subroutines, conveniently scales a set of variables (by applying logarithms, for instance) and proceeds by

finding succesive polynomial regressions (by calling REGRE1) from the order 1 up to a maximum order NMX. That regression having the least standard deviation is selected as the best, and its coefficients returned. After some tests a value of NMX = 6 was fixed based on the fact that larger values are not only of little practical value but, in present experiments, may be reflecting random variations.

Subroutine REGFAC, called by the Main program, is a regression facility incorporated into the program to serve as an auxiliary to further analysis by the investigator. The user may enter a number of data pairs when prompted at the terminal screen, and select, from a limited number of options, a particular scaling in terms of logarithms. Then subroutine BSTREG is called to obtain a best fit. For instance, it was used to obtain a polynomial regression of viscosity as a function of temperature. At present, it does not include a plotting facility. It would be relatively easy, by using a number of other routines included in the program, to expand this facility into an additional powerful tool for analysis and documentation.

4.7 Boundary Layer Analyses

Subroutine DISTRI is the only subroutine called by the Main program that has been written for the sole purpose of investigating steady-state turbulent boundary layers in a laboratory flume (together with all subroutines it calls). Its purpose, in contrast with previous pointwise statistical subroutines, is to study distributions of velocities across the boundary layer. It does some tasks by itself, including rearranging data points from bottom to surface, correcting for bottom proximity (corrected values are

printed in output file FN12, section 4.10), finding the maximum or reference velocity, estimating the boundary layer thickness as corresponding with the maximum velocity, and filtering the data. It also calls several other important subroutines.

A best polynomial regression fitting is obtained by DISTRI, after bottom-proximity correction, by calling the auxiliary subroutine BSTREG (u vs. ln(y)). Then, by trial and error, the boundary layer thickness and the maximum velocity are found. These often correspond to the surface level in a flume. Some data points can contain errors due to mishandling of flume operation or some other practice that deviates from specified experimental conditions. For this reason, the aforementioned filtering procedure is carried out as follows, after a side-wall correction and normalization (performed by subroutine WALL) are done. First a new best polynomial is found for the new set of u+ vs. ln(y+) points. Then for each point, the relative error is determined as defined by the following simple expression, ERR = [u+(data) - u+(poly)] / u+(poly). After a series of tests, a tolerance was fixed as TOL = 0.5 % . It was found that proceeding very carefully in experiments, almost all points fall into tolerance, and the resulting set of points permitts the subsequent analysis. On the other hand, a hasty positioning of the probe, for instance, or a too short period of data collection, would make a data point exceed the tolerance. Another problem can be the incidence of a single data point containing a gross mistake. Since measuring probe positioning was read on a micrometer by an operator, a wrong reading or wrong actual position would lead to a distortion of the fitting polynomial altering the set of relative errors. To avoid this problem, only that point exceeding TOL by the maximum is eliminated at any

one time, and each time a new best-fitting polynomial and set of relative errors is computed again, until all remaining points satisfy the tolerance. For instance, in one case there was at first 7 points with ERR > TOL from a total of 48 points; after eliminating only 3, the remaining 45 satisfied ERR < TOL, and one of the points that originally satisfied the tolerance was one of the three eliminated. This task is properly documented in FN12 (Section 4.10). The final u+ versus y+ data points is tabulated as shown in FN12.

Subroutine WALL, called by DISTRI, applies Johnson's method for side wall correction (Theory given in Chapter 2) and normalizes the data in terms of the dimensionless parameters u+ and y+. WALL asks the user for five parameters: the temperature, the flow depth, the discharge manometer reading, the water surface slope, and the channel width. A fter the values are entered, they are displayed on the terminal screen and the user is given opportunity to change or confirm them. WALL then computes the viscosity (from a polynomial regression contained in the program), the discharge, hydraulic ratios (global, bed and wall), et cetera (The Reynolds/friction factor ratio is also interpolated from a polynomial regression). The bed shear velocity is finally used to normalize the equations, thus introducing a correction accounting for wall effects (Section 4.10).

Subroutine ORIGIN, called by DISTRI, implements the Perry-Joubert search of virtual origin (Theory in Chapter 2) and also computes the Karman coefficient, the intercept and the wake-strength parameter for a null virtual origin assumption. The virtual origin search is conducted for different sub-layer thicknesses, in an attempt to visualize and quantify the influence of inadvertently including some portion of the wake in the region assumed

logarithmic. Such inclusion will distort the results, and the aim here is to quantify that distortion. Since the measurements conducted in the course of this research did not permit a proper application of the procedure to the near-bed logarithmic asymptote, this analysis could not be further developed, although it will be possible with better data. Dimensionless variables are used throughout the entire procedure.

The automated analysis begins with the 4 points nearest to the bed. The sub-layer thickness fixed this way is computed in terms of a percentage of the boundary layer thickness. Both an initial $\epsilon+$ virtual origin and $\Delta\epsilon+$ increment are estimated by scaling an arbitrary value of 1 mm.. A quadratic regression is obtained for $u+$ vs. $\ln(y+ + \epsilon+)$. The regression coefficient c_2 corresponding to the quadratic term serves as an indicator for the procedure: while finding new regressions, $\epsilon+$ is incremented by $\Delta\epsilon+$ until a change of sign in c_2 is registered. At that point the increment is modified according to the assignment $\Delta\epsilon+ = -0.4*\Delta\epsilon+$, i.e. the search is reversed and refined. The procedure ends when the magnitude of c_2 falls below a tolerance value, meaning that a linear regression has actually been attained.

If desired, the points and the final linear regression are plotted in a dimensionless graph by using the plotting routines described in 4.8. The same graph contains the original y+ vs. u+ data points and best polynomial regression. Additional information is written in the graph, including the new estimate of the Karman coefficient (the inverse of the slope of the new linear regression) and the corresponding intercept and virtual-origin parameter $\epsilon+$ (Figure 4.1). The procedure is repeated, adding one point at a time, for up to 10 points. Thus the graph would contain seven linear

regressions and their respective parameters. The graph would also contain the bed shear velocity and the kinematic viscosity used in the computations (as opportunly obtained by the subroutine WALL). At this point the user may optionally continue the procedure for another additional seven points (hence new regressions) that would be plotted in a second graph (Figure 4.2) or may restart the procedure, or end it. If the operator decides to produce a second graph, the same stop-or-continue opportunity will be available at its end and so forth until all data points have been considered (Figure 4.3), in which case the program ends the procedure. Nonetheless, the user will be able to restart the virtual origin search or continue with the succeeding procedure. If the user opts not to obtain the afore-discussed plots, the computations are carried out anyway from 4 points at first, up to the total number of data points.

A number of parameters and arrays are computed at the same time, and sent to FN12 for each virtual-origin solution, including (see example in section 4.10) the ratio of sub-layer thickness h to boundary layer thickness w in terms of percentage, PER = H/D*100 (which does not includes e), standard error of estimate of the final linear regression, SD, the final second-order regression coefficient, B(2) (to check the correctness of the solution), the virtual-origin distance, EPS or e (in meters), the dimensionless virtual-origin distance, EP1 or e+, the intercept A, the Karman coefficient VK or k, the wake-strength parameter, PI or <, the dimensionless boundary-layer thickness, D+ or w+ and the dimensionless reference flow velocity, UM+ or U_m+. For each data point, a set of resulting variables is printed in tabulated form (the computer printout reads Y+ instead Y+ + EP1 and D+ instead D+ + EP1 for simplicity), including the velocity defect U_m+ - U+, an

estimate of the wake (deceptive when points of the wake region are included in the estimation of $\epsilon+$), and the corresponding wake region velocity values predicted by Coles' and Finley's laws.

The ratio H/D is stored and used next in conjunction with the plotting of κ, A, $\epsilon+$ and Π against $\ln(h/\delta)$ (Figure 4.4), which is executed by the subroutine KARMAN, called by DISTRI. In this figure (the 4 graphs are drawn on a single sheet), the effects of the wake can be studied (see the analysis in Chapter 1), when jointly considered with the next figure. In Figure 4.4 both the obtained points and the corresponding best-polynomial regressions obtained by subroutine BSTREG are drawn. Under the Title "Plot of functions upon relative depth" (Section 4.10), the standard error of estimate obtained in the best-regression search and the regression coefficients are printed for each of the four functions plotted in Figure 4.4.

A more classical analysis is done at the end of the routine ORIGIN by ignoring the virtual-origin distance. An arbitrary closest-to-the-wall 10% of the boundary layer is taken and a best-regression is obtained as the "logarithmic law of the wall". If this best regression is not in fact a linear function, this would serve as an indication than this expected behaviour is not confirmed by the measurements, perhaps because data points from the wake are included. Nonetheless, in this procedure a linear regression is obtained, and the Karman coefficient, the intercept, and the wake-strength parameter are computed. Next the velocity-defect and wake are computed, as well as Coles' and Finley's predictions for the wake. These values are printed are tabulated in FN12 as before, under the title "Law type 1 , u+.vs.ln(y+) for null virtual origin" (section 4.10), after the virtual-

origin search print-out.

The entire velocity distribution, the velocity-defect distribution, the logarithmic law-of-the wall, the measured wake, and Coles' and Finley's laws thus computed by ORIGIN are then plotted (Figure 4.5) on a single sheet by the subroutine DEFECT (called by DISTRI). As before, best-fitting polynomial regressions are used (computed by BSTREG).

Under the Title "Plot of functions with y+ computed from bed" (section 4.10), the standard error of estimate obtained in the best-regression search and the regression coefficients are printed for each of the four functions plotted in Figure 4.5. The wake function plot serves to determine the quality of the wake predictors. The velocity-defect distribution establishes whether a logarithmic-overlap region is present in the measurements or not. The Karman, intercept and wake-strength parameters are also printed in the same figure.

4.8 Plotting routines

A set of routines has been prepared to allow the plotting of the graphs described above in different machines. Subroutine PLO opens and closes drawings on a Hewlett-Packard or Tektronix multipen plotter (option 1), a Tektronix terminal screen and Tektronix attached hardcopier (option 2) or an off-line Versatec hardcopier (option 3).

Subroutine HPLOT2, called by ORIGIN, KARMAN and DEFECT, does the actual plotting, including frames, axis, figures, point symbols, curves and

subtitles. It has a number of parameters, described in comment cards in the source program, that provides a great flexibility (although it results in a somewhat cryptic code) allowing its use for different purposes.

Subroutine LIMITS, called by ORIGIN, KARMAN and DEFECT, find minimum and maximum values for the plotting arrays, allowing for a margin around the figure to be included in the drawing frame. Subroutine SCALE1, called by HPLOT2, scales the plotting arrays to the proper dimensions fitting the different actual drawing frames and positioning. It uses values computed by LIMITS.

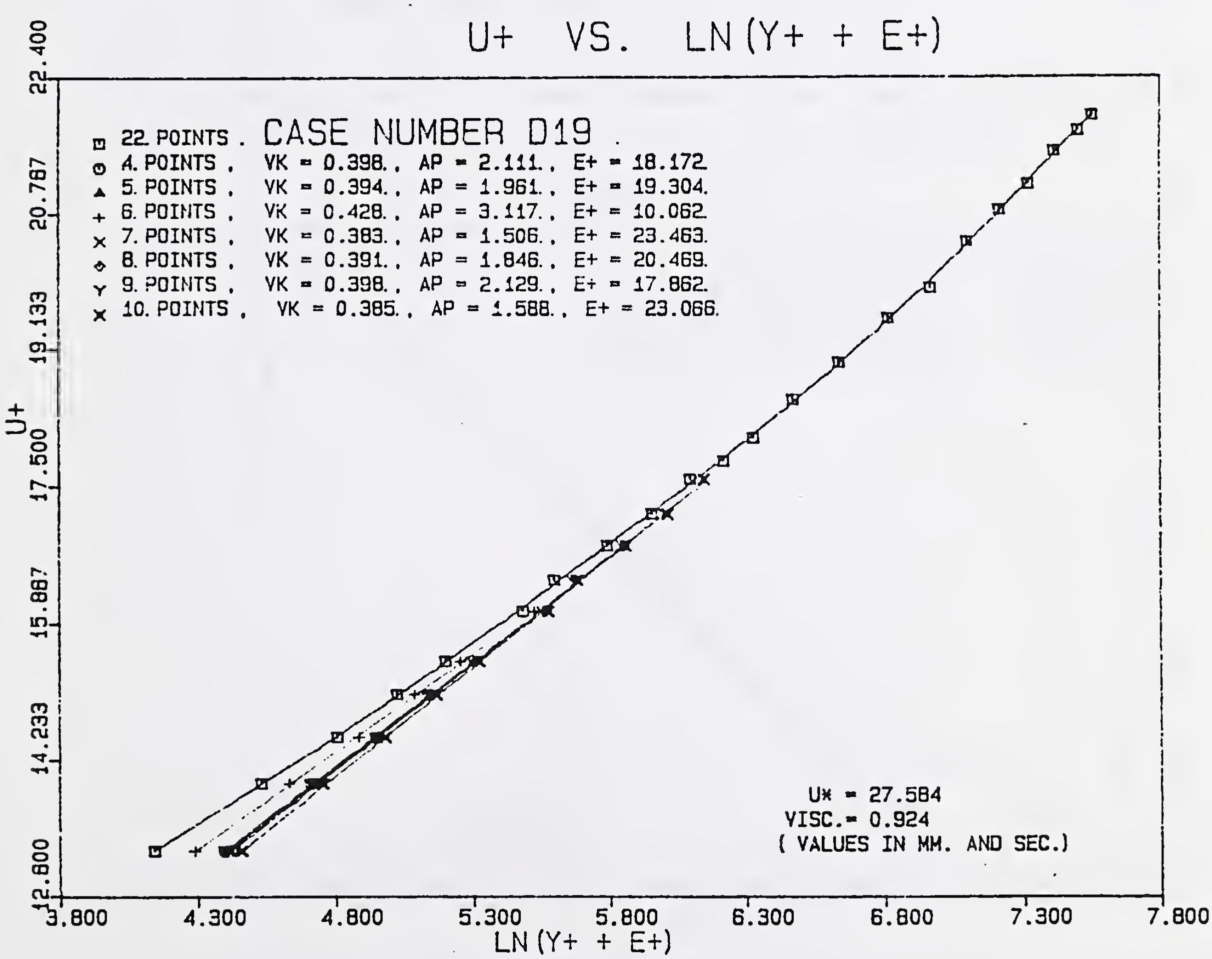


Figure 4.1: Virtual-origin search example using 4 up to 10 points.

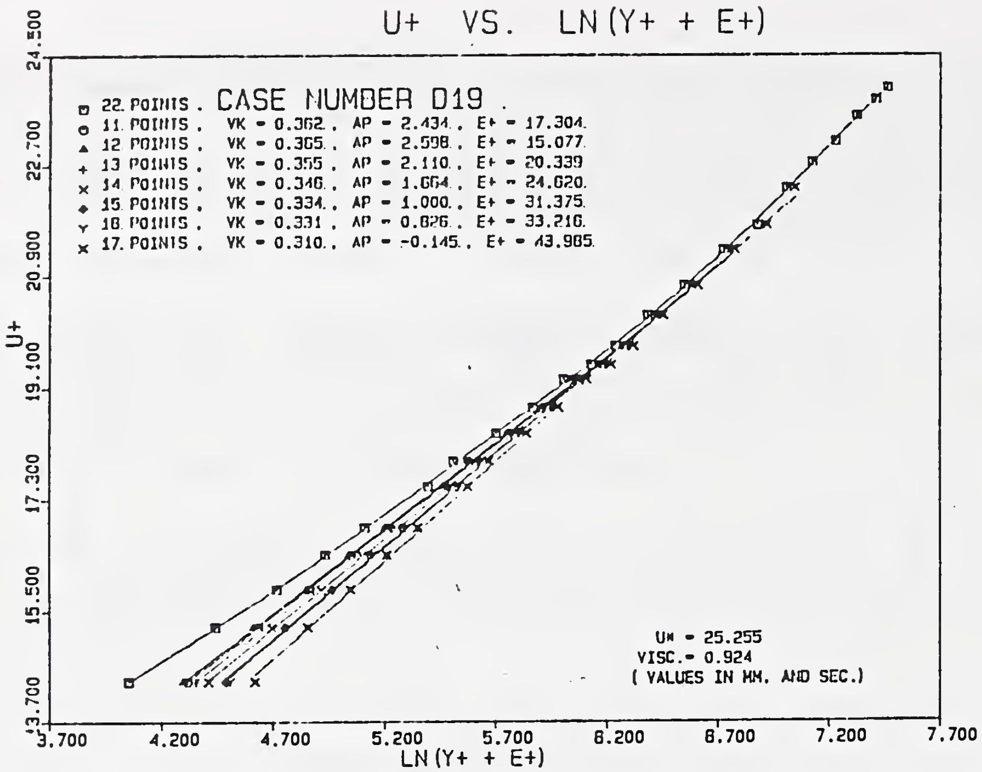


Figure 4.2: Virtual-origin search example using 11 up to 17 points.

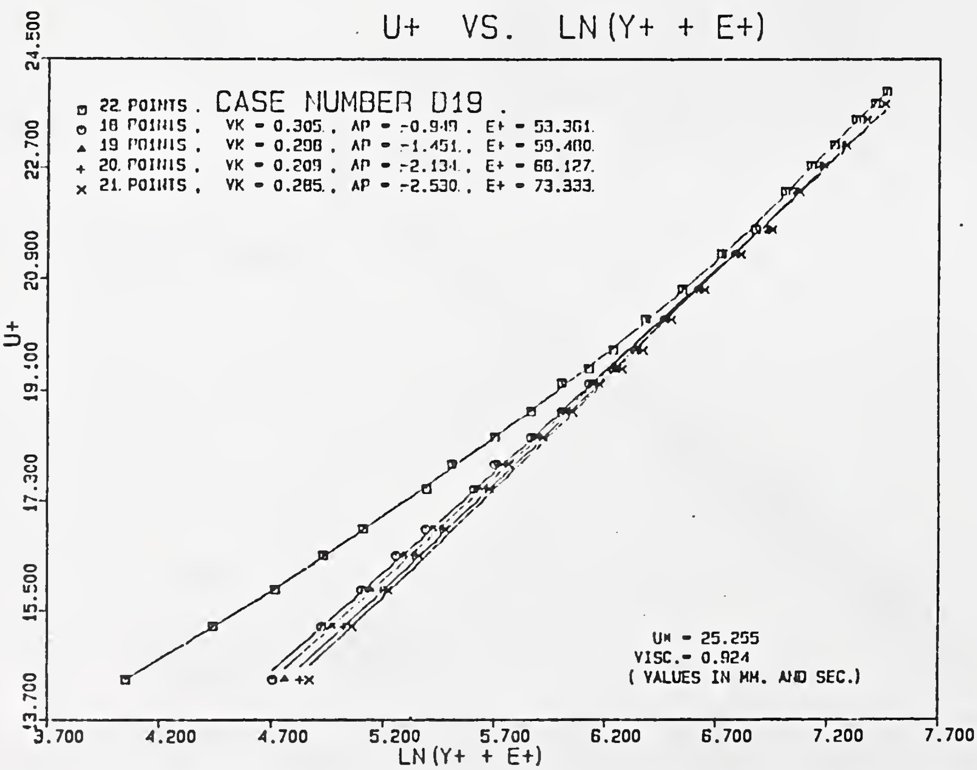


Figure 4.3: Virtual-origin search example using 18 up to 21 points.

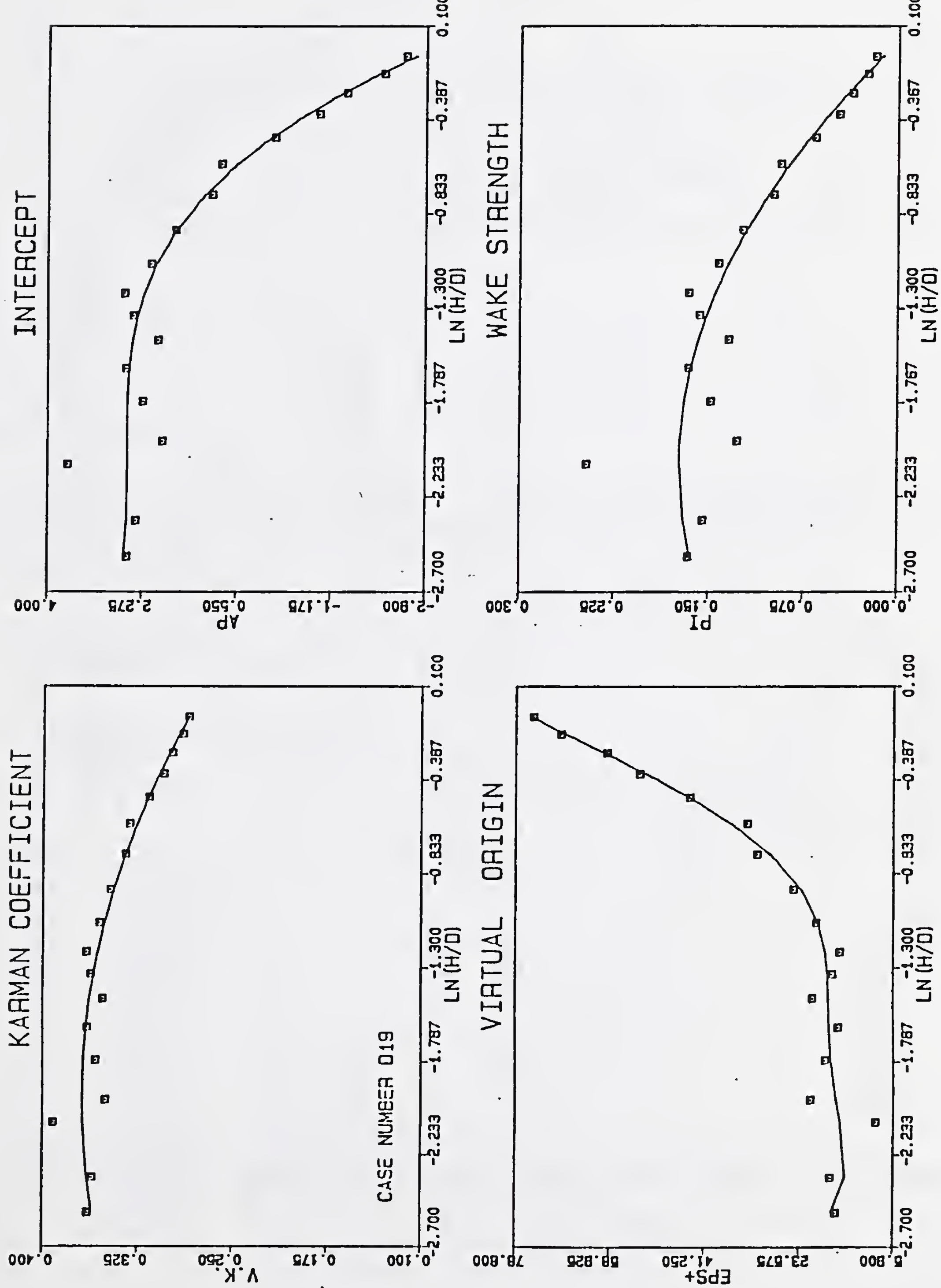


Figure 4.4: Plot of functions upon relative depth.

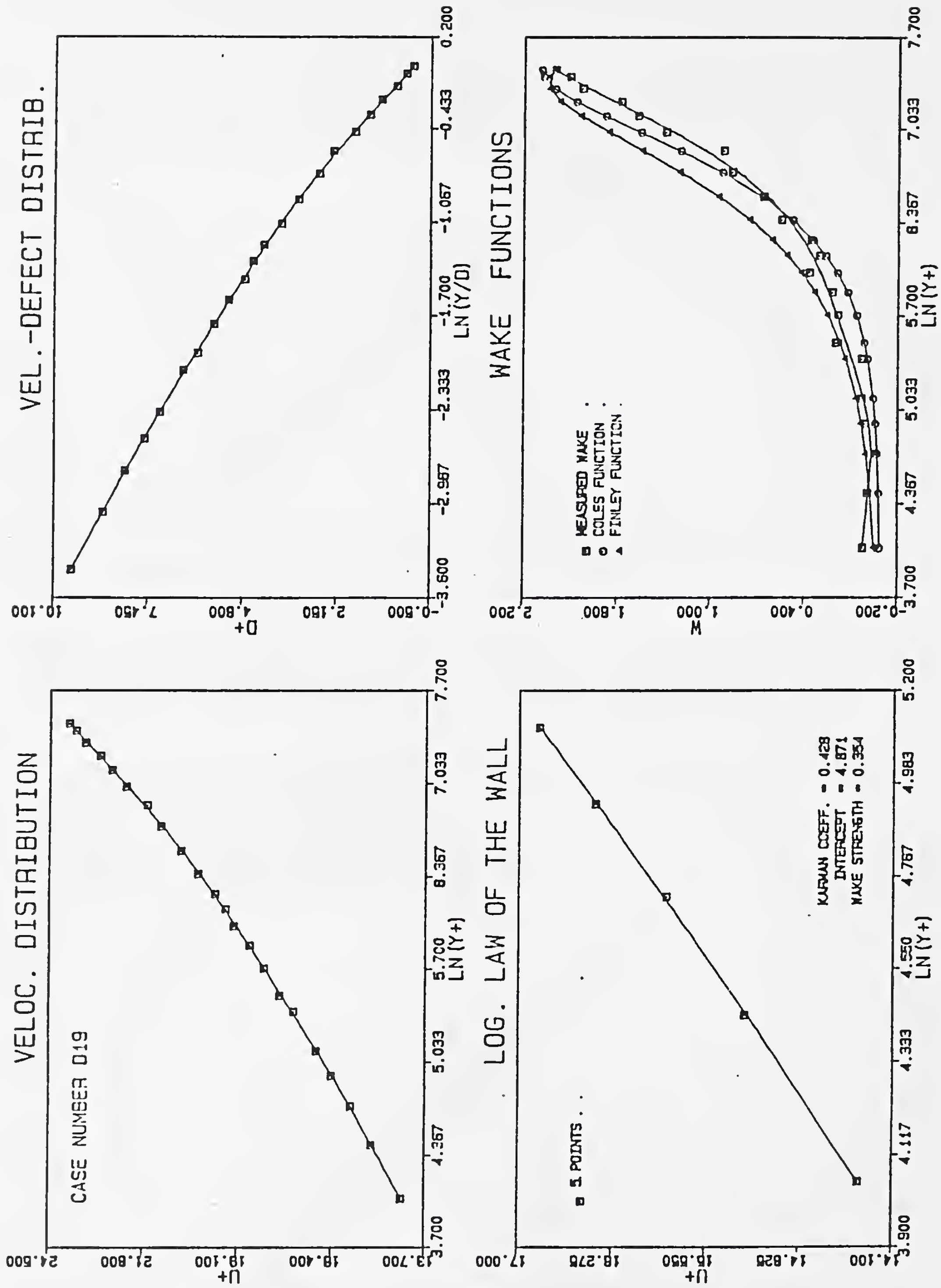


Figure 4.5: Plot of functions with y+ computed from bed (null virtual origin)

4.9 Example of FN12 during data acquisition and Statistical Analysis

```
*****************************************************
***   USDA SEDIMENTATION LABORATORY, OXFORD      ***
***     P R O G R A M      V E L M E A S         ***
***   MEASUREMENT AND STATISTICAL ANALYSIS       ***
***     OF VELOCITIES IN TURBULENT FLOWS         ***
***              VERSION 1 (1985)                ***
*****************************************************

ELAPSED TIME             301.41500 SECONDS

"Y" PROBE POSITION:        1.550

SEA 02/13/86 #19

STATISTICAL ANALYSIS

NUMBER OF SAMPLES          :    30000.
SECONDS FOR DELAY          :     0.01
MINIMUM VOLTAGE FOUND      =     0.105 VOLTS
MAXIMUM VOLTAGE FOUND      =     0.374 VOLTS
DATA IS IN MULTIPLES OF          0.005 VOLTS

  30000.-SAMPLES MEAN:        XM=      0.229
SAMPLE STANDARD DEVIATION:    SM=      0.042

THE  54 FREQUENCIES OBTAINED :

NUM   VALUE       FREQ               GRAPH ( FROM 0.0 TO 0.05 )
                                 ( SCALE IS    ! =    28.3 SAMPLES )

  1   0.105    0.00010    |                                        |
  2   0.110    0.00027    |                                        |
  3   0.115    0.00023    |                                        |
  4   0.120    0.00063    |                                        |
  5   0.125    0.00110    |!                                       |
  6   0.130    0.00140    |!                                       |
  7   0.135    0.00240    |!!                                      |
  8   0.140    0.00530    |!!!!!                                   |
  9   0.145    0.00630    |!!!!!!                                  |
 10   0.150    0.00840    |!!!!!!!!                                |
 11   0.155    0.01383    |!!!!!!!!!!!!!!                          |
 12   0.160    0.01380    |!!!!!!!!!!!!!!                          |
 13   0.165    0.01903    |!!!!!!!!!!!!!!!!!!!!                    |
 14   0.170    0.02323    |!!!!!!!!!!!!!!!!!!!!!!!!                |
 15   0.175    0.02707    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!            |
 16   0.180    0.02960    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!         |
 17   0.185    0.03170    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!       |
```

```
 18   0.190   0.03547   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!             |
 19   0.195   0.04027   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!        |
 20   0.200   0.04467   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
 21   0.205   0.04710   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
 22   0.210   0.04460   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
 23   0.215   0.04370   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!    |
 24   0.220   0.04473   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
 25   0.225   0.04300   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!     |
 26   0.230   0.04330   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!     |
 27   0.235   0.04233   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 28   0.240   0.04210   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 29   0.245   0.03807   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
 30   0.250   0.03633   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!            |
 31   0.255   0.03453   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!              |
 32   0.260   0.03167   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                 |
 33   0.265   0.02683   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!                      |
 34   0.270   0.02737   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                     |
 35   0.275   0.02370   |!!!!!!!!!!!!!!!!!!!!!!!!!                         |
 36   0.280   0.02173   |!!!!!!!!!!!!!!!!!!!!!!!                           |
 37   0.285   0.02017   |!!!!!!!!!!!!!!!!!!!!!                             |
 38   0.290   0.01493   |!!!!!!!!!!!!!!!                                   |
 39   0.295   0.01447   |!!!!!!!!!!!!!!!                                   |
 40   0.300   0.01300   |!!!!!!!!!!!!!                                     |
 41   0.305   0.00930   |!!!!!!!!!                                         |
 42   0.310   0.00757   |!!!!!!!!                                          |
 43   0.315   0.00653   |!!!!!!                                            |
 44   0.320   0.00600   |!!!!!!                                            |
 45   0.325   0.00333   |!!!                                               |
 46   0.330   0.00267   |!!                                                |
 47   0.335   0.00183   |!                                                 |
 48   0.340   0.00133   |!                                                 |
 49   0.345   0.00110   |!                                                 |
 50   0.350   0.00070   |                                                  |
 51   0.355   0.00027   |                                                  |
 52   0.360   0.00043   |                                                  |
 53   0.365   0.00020   |                                                  |
 54   0.370   0.00027   |                                                  |
                        =======
            SUM =       1.00000

VALUES FOUND THROUGH THE CURVE OF FREQUENCIES:
           MEAN      =     0.227
STANDARD DEVIATION   =     0.028
          MEDIAN     =     0.222
           MODE      =     0.205
         SKEWNESS    =     0.018
         KURTOSIS    =    -2.610

MOMENTS ABOUT THE ORIGEN AT ZERO:
                  FIRST    =     0.226577
                  SECOND   =     0.053102
                  THIRD    =     0.012848
                  FOURTH   =     0.003203
MOMENTS ABOUT THE MEAN (AND SHEPARD CORRECTIONS) :
                  FIRST    =    -0.002137
```

```
                 SECOND   =     0.000792              CORRECT.=     0.000789
                 THIRO    =     0.000341
                 FOURTH   =    -0.000094              CORRECT.=    -0.000094
COEFFICIENT BETA ANO GAMMA:
                 BETA 1   =   236.432245              BETA 2   =     0.390483
                 GAMMA 1 =     15.376353              GAMMA 2 =    -2.609517



                  ************************************************
                  ***  USOA SEOIMENTATION LABORATORY, OXFORD  ***
                  ***     P R O G R A M     V E L M E A S     ***
                  ***   MEASUREMENT ANO STATISTICAL ANALYSIS  ***
                  ***     OF VELOCITIES IN TURBULENT FLOWS    ***
                  ***            VERSION 1 (1985)             ***
                  ************************************************

ELAPSED TIME             301.88000 SECONOS

"Y" PROBE POSITION:        2.550

C

STATISTICAL ANALYSIS

NUMBER OF SAMPLES          :    30000.
SECONOS FOR OELAY          :     0.01
MINIMUM VOLTAGE FOUNO      =     0.139 VOLTS
MAXIMUM VOLTAGE FOUND      =     0.423 VOLTS
DATA IS IN MULTIPLES OF          0.005 VOLTS

  30000.-SAMPLES MEAN:       XM=      0.258
SAMPLE STANOARO OEVIATION:   SM=      0.044

THE  57 FREQUENCIES OBTAINEO :

NUM    VALUE       FREQ               GRAPH ( FROM 0.0 TO 0.05 )
                                ( SCALE IS    ! =    27.3 SAMPLES )

  1    0.139    0.00087    |                                                          |
  2    0.144    0.00097    |!                                                         |
  3    0.149    0.00187    |!!                                                        |
  4    0.154    0.00280    |!!!                                                       |
  5    0.159    0.00403    |!!!!                                                      |
  6    0.164    0.00673    |!!!!!!!                                                   |
  7    0.169    0.00770    |!!!!!!!!                                                  |
  8    0.174    0.00830    |!!!!!!!!!                                                 |
  9    0.179    0.01153    |!!!!!!!!!!!!                                              |
 10    0.184    0.01510    |!!!!!!!!!!!!!!!!                                          |
 11    0.189    0.01930    |!!!!!!!!!!!!!!!!!!!!!                                     |
```

```
12   0.194   0.01827   |!!!!!!!!!!!!!!!!!!!!                             |
13   0.199   0.01907   |!!!!!!!!!!!!!!!!!!!!                             |
14   0.204   0.02303   |!!!!!!!!!!!!!!!!!!!!!!!!!                        |
15   0.209   0.02917   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                 |
16   0.214   0.03177   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!               |
17   0.219   0.03033   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                |
18   0.224   0.03633   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
19   0.229   0.03847   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!       |
20   0.234   0.03750   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!        |
21   0.239   0.04177   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!    |
22   0.244   0.04280   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
23   0.249   0.04553   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
24   0.254   0.04553   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
25   0.259   0.04497   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
26   0.264   0.04467   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
27   0.269   0.04427   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! |
28   0.274   0.04050   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!     |
29   0.279   0.03917   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
30   0.284   0.03720   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!         |
31   0.289   0.03457   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!            |
32   0.294   0.02723   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                    |
33   0.299   0.02490   |!!!!!!!!!!!!!!!!!!!!!!!!!!!                      |
34   0.304   0.02250   |!!!!!!!!!!!!!!!!!!!!!!!!                         |
35   0.309   0.01953   |!!!!!!!!!!!!!!!!!!!!!                            |
36   0.314   0.01750   |!!!!!!!!!!!!!!!!!!!                              |
37   0.319   0.01627   |!!!!!!!!!!!!!!!!!                                |
38   0.324   0.01270   |!!!!!!!!!!!!!                                    |
39   0.329   0.00923   |!!!!!!!!!!                                       |
40   0.334   0.00923   |!!!!!!!!!!                                       |
41   0.339   0.00740   |!!!!!!!!                                         |
42   0.344   0.00600   |!!!!!!                                           |
43   0.349   0.00463   |!!!!!                                            |
44   0.354   0.00447   |!!!!                                             |
45   0.359   0.00357   |!!!                                              |
46   0.364   0.00323   |!!!                                              |
47   0.369   0.00277   |!!!                                              |
48   0.374   0.00177   |!                                                |
49   0.379   0.00100   |!                                                |
50   0.384   0.00080   |                                                 |
51   0.389   0.00020   |                                                 |
52   0.394   0.00007   |                                                 |
53   0.399   0.00013   |                                                 |
54   0.404   0.00013   |                                                 |
55   0.409   0.00010   |                                                 |
56   0.414   0.00027   |                                                 |
57   0.419   0.00027   |                                                 |
             =======
       SUM = 1.00000

VALUES FOUND THROUGH THE CURVE OF FREQUENCIES:
             MEAN      =     0.255
STANDARD DEVIATION =     0.023
            MEDIAN     =     0.252
             MODE      =     0.254
           SKEWNESS    =     0.543
```

```
         KURTOSIS  =  -335.087

MOMENTS ABOUT THE ORIGEN AT ZERO:
                FIRST    =     0.255194
                SECOND   =     0.067062
                THIRD    =     0.018115
                FOURTH   =     0.005022
MOMENTS ABOUT THE MEAN (AND SHEPARD CORRECTIONS) :
                FIRST    =    -0.002735
                SECOND   =     0.000534          CORRECT.=     0.000532
                THIRD    =     0.000543
                FOURTH   =    -0.000177          CORRECT.=    -0.000177
COEFFICIENT BETA AND GAMMA:
                BETA 1   = 1953.969727           BETA 2   = -332.087206
                GAMMA 1 =    44.203730           GAMMA 2  = -335.087206
```

```
                 **********************************************
                 ***  USDA SEDIMENTATION LABORATORY, OXFORD  ***
                 ***     P R O G R A M     V E L M E A S     ***
                 ***  MEASUREMENT AND STATISTICAL ANALYSIS   ***
                 ***     OF VELOCITIES IN TURBULENT FLOWS    ***
                 ***             VERSION 1 (1985)            ***
                 **********************************************

ELAPSED TIME               302.09500 SECONDS

"Y" PROBE POSITION:          3.550


STATISTICAL ANALYSIS

NUMBER OF SAMPLES           :   30000.
SECONDS FOR DELAY           :    0.01
MINIMUM VOLTAGE FOUND       =    0.149 VOLTS
MAXIMUM VOLTAGE FOUND       =    0.448 VOLTS
DATA IS IN MULTIPLES OF          0.005 VOLTS

  30000.-SAMPLES MEAN:        XM=      0.279
SAMPLE STANDARD DEVIATION:    SM=      0.048

THE  60 FREQUENCIES OBTAINED :

NUM    VALUE      FREQ                GRAPH ( FROM 0.0 TO 0.04 )
                               ( SCALE IS    ! =    24.4 SAMPLES )

  1    0.149    0.00050    |                                         |
  2    0.154    0.00017    |                                         |
```

```
 3   0.159   0.00097   |!                                                |
 4   0.164   0.00253   |!!!                                              |
 5   0.169   0.00353   |!!!!                                             |
 6   0.174   0.00623   |!!!!!!!                                          |
 7   0.179   0.00667   |!!!!!!!!                                         |
 8   0.184   0.00660   |!!!!!!!!                                         |
 9   0.189   0.00613   |!!!!!!!                                          |
10   0.194   0.00990   |!!!!!!!!!!!!                                     |
11   0.199   0.01140   |!!!!!!!!!!!!!!                                   |
12   0.204   0.01353   |!!!!!!!!!!!!!!!!                                 |
13   0.209   0.01653   |!!!!!!!!!!!!!!!!!!!!                             |
14   0.214   0.02083   |!!!!!!!!!!!!!!!!!!!!!!!!!                        |
15   0.219   0.02297   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!                     |
16   0.224   0.02843   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!              |
17   0.229   0.02997   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!             |
18   0.234   0.03183   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
19   0.239   0.03363   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!        |
20   0.244   0.03813   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
21   0.249   0.03810   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
22   0.254   0.03933   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! |
23   0.259   0.03907   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! |
24   0.264   0.03790   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!   |
25   0.269   0.03600   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!     |
26   0.274   0.03623   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!     |
27   0.279   0.04060   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
28   0.284   0.03690   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!    |
29   0.289   0.03527   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
30   0.294   0.03503   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
31   0.299   0.03443   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!       |
32   0.304   0.03153   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!           |
33   0.309   0.03073   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!            |
34   0.314   0.03113   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!           |
35   0.319   0.02777   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!               |
36   0.324   0.02503   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                   |
37   0.329   0.02243   |!!!!!!!!!!!!!!!!!!!!!!!!!!!                      |
38   0.334   0.01940   |!!!!!!!!!!!!!!!!!!!!!!!                          |
39   0.339   0.01850   |!!!!!!!!!!!!!!!!!!!!!!                           |
40   0.344   0.01580   |!!!!!!!!!!!!!!!!!!!                              |
41   0.349   0.01343   |!!!!!!!!!!!!!!!!                                 |
42   0.354   0.01217   |!!!!!!!!!!!!!!                                   |
43   0.359   0.00883   |!!!!!!!!!!                                       |
44   0.364   0.00890   |!!!!!!!!!!                                       |
45   0.369   0.00663   |!!!!!!!!                                         |
46   0.374   0.00683   |!!!!!!!!                                         |
47   0.379   0.00560   |!!!!!!                                           |
48   0.384   0.00370   |!!!!                                             |
49   0.389   0.00290   |!!!                                              |
50   0.394   0.00167   |!!                                               |
51   0.399   0.00123   |!                                                |
52   0.404   0.00130   |!                                                |
53   0.409   0.00150   |!                                                |
54   0.414   0.00117   |!                                                |
55   0.419   0.00050   |                                                 |
56   0.424   0.00053   |                                                 |
57   0.429   0.00047   |                                                 |
```

```
 58   0.434   0.00053   |                                                                   |
 59   0.439   0.00030   |                                                                   |
 60   0.444   0.00010   |                                                                   |
              =======
       SUM = 1.00000

VALUES FOUND THROUGH THE CURVE OF FREQUENCIES:
          MEAN      =      0.276
STANDARD DEVIATION =       0.028
         MEDIAN    =       0.272
          MODE     =       0.279
        SKEWNESS   =       0.618
        KURTOSIS   =   -277.495

MOMENTS ABOUT THE ORIGEN AT ZERO:
              FIRST    =     0.276306
              SECOND   =     0.078686
              THIRD    =     0.023057
              FOURTH   =     0.006940
MOMENTS ABOUT THE MEAN (AND SHEPARD CORRECTIONS) :
              FIRST    =   -0.002765
              SECOND   =     0.000805          CORRECT.=     0.000803
              THIRD    =     0.000649
              FOURTH   =   -0.000225           CORRECT.=    -0.000225
COEFFICIENT BETA AND GAMMA:
              BETA 1   =  812.382992           BETA 2   = -274.495117
              GAMMA 1  =   28.502333           GAMMA 2  = -277.495117




               ************************************************
               ***  USDA SEDIMENTATION LABORATORY, OXFORD  ***
               ***    P R O G R A M     V E L M E A S      ***
               ***   MEASUREMENT AND STATISTICAL ANALYSIS  ***
               ***     OF VELOCITIES IN TURBULENT FLOWS    ***
               ***            VERSION 1 (1985)             ***
               ************************************************

ELAPSED TIME              300.64500 SECONDS

"Y" PROBE POSITION:         4.550


STATISTICAL ANALYSIS

NUMBER OF SAMPLES          :   30000.
SECONDS FOR DELAY          :    0.01
MINIMUM VOLTAGE FOUND      =    0.164 VOLTS
MAXIMUM VOLTAGE FOUND      =    0.465 VOLTS
DATA IS IN MULTIPLES OF         0.005 VOLTS
```

```
  30000.-SAMPLES MEAN:        XM=       0.299
SAMPLE STANDARD DEVIATION:   SM=       0.051


THE  61 FREQUENCIES OBTAINED :

NUM    VALUE       FREQ                 GRAPH ( FROM 0.0 TO 0.04 )
                                 ( SCALE IS     ! =     25.3 SAMPLES )

  1    0.164    0.00047    |                                                  |
  2    0.169    0.00120    |!                                                 |
  3    0.174    0.00260    |!!!                                               |
  4    0.179    0.00207    |!!                                                |
  5    0.184    0.00297    |!!!                                               |
  6    0.189    0.00307    |!!!                                               |
  7    0.194    0.00423    |!!!!!                                             |
  8    0.199    0.00560    |!!!!!!                                            |
  9    0.204    0.00647    |!!!!!!!                                           |
 10    0.209    0.00903    |!!!!!!!!!!                                        |
 11    0.214    0.01233    |!!!!!!!!!!!!!!                                    |
 12    0.219    0.01337    |!!!!!!!!!!!!!!!                                   |
 13    0.224    0.01363    |!!!!!!!!!!!!!!!!                                  |
 14    0.229    0.01780    |!!!!!!!!!!!!!!!!!!!!!                             |
 15    0.234    0.02093    |!!!!!!!!!!!!!!!!!!!!!!!!                          |
 16    0.239    0.02483    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                     |
 17    0.244    0.02760    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                  |
 18    0.249    0.03160    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!             |
 19    0.254    0.02987    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!               |
 20    0.259    0.03303    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!           |
 21    0.264    0.03307    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!           |
 22    0.269    0.03427    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
 23    0.274    0.03717    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 24    0.279    0.04097    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!  |
 25    0.284    0.03827    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!     |
 26    0.289    0.04217    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!|
 27    0.294    0.03730    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 28    0.299    0.03723    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 29    0.304    0.03727    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 30    0.309    0.03620    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!        |
 31    0.314    0.03227    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!            |
 32    0.319    0.03033    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!               |
 33    0.324    0.03297    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!           |
 34    0.329    0.02677    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                   |
 35    0.334    0.02573    |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                    |
 36    0.339    0.02310    |!!!!!!!!!!!!!!!!!!!!!!!!!!!                       |
 37    0.344    0.02297    |!!!!!!!!!!!!!!!!!!!!!!!!!!!                       |
 38    0.349    0.02177    |!!!!!!!!!!!!!!!!!!!!!!!!!                         |
 39    0.354    0.02083    |!!!!!!!!!!!!!!!!!!!!!!!!                          |
 40    0.359    0.01683    |!!!!!!!!!!!!!!!!!!!                               |
 41    0.364    0.01427    |!!!!!!!!!!!!!!!!                                  |
 42    0.369    0.01623    |!!!!!!!!!!!!!!!!!!!                               |
 43    0.374    0.01667    |!!!!!!!!!!!!!!!!!!!                               |
 44    0.379    0.01100    |!!!!!!!!!!!!!                                     |
 45    0.384    0.00893    |!!!!!!!!!!                                        |
```

```
 46   0.389   0.00747   |!!!!!!!!!                                                           |
 47   0.394   0.00647   |!!!!!!!!                                                            |
 48   0.399   0.00617   |!!!!!!!!                                                            |
 49   0.404   0.00477   |!!!!!!                                                              |
 50   0.409   0.00403   |!!!!                                                                |
 51   0.414   0.00343   |!!!!                                                                |
 52   0.419   0.00283   |!!!                                                                 |
 53   0.424   0.00183   |!!                                                                  |
 54   0.429   0.00123   |!                                                                   |
 55   0.434   0.00090   |!                                                                   |
 56   0.439   0.00090   |!                                                                   |
 57   0.444   0.00057   |                                                                    |
 58   0.449   0.00063   |                                                                    |
 59   0.454   0.00080   |                                                                    |
 60   0.459   0.00067   |                                                                    |
 61   0.464   0.00003   |                                                                    |
                =======
        SUM = 1.00000

VALUES FOUND THROUGH THE CURVE OF FREQUENCIES:
         MEAN     =      0.296
STANDARD DEVIATION =     0.030
          MEDIAN   =     0.291
           MODE    =     0.289
         SKEWNESS  =     0.624
         KURTOSIS  =  -267.974

MOMENTS ABOUT THE ORIGEN AT ZERO:
                 FIRST    =    0.296310
                 SECOND   =    0.090362
                 THIRD    =    0.028322
                 FOURTH   =    0.009111
MOMENTS ABOUT THE MEAN (AND SHEPARD CORRECTIONS) :
                 FIRST    =   -0.002751
                 SECOND   =    0.000925          CORRECT.=     0.000922
                 THIRD    =    0.000745
                 FOURTH   =   -0.000276          CORRECT.=    -0.000276
COEFFICIENT BETA AND GAMMA:
                 BETA 1   =  707.741425          BETA 2   = -264.974300
                 GAMMA 1 =    26.603410          GAMMA 2 = -267.974300


                    ***********************************************
                    ***   USDA SEDIMENTATION LABORATORY, OXFORD   ***
                    ***      P R O G R A M    V E L M E A S       ***
                    ***   MEASUREMENT AND STATISTICAL ANALYSIS    ***
                    ***     OF VELOCITIES IN TURBULENT FLOWS      ***
                    ***             VERSION 1 (1985)              ***
                    ***********************************************
```

```
ELAPSED TIME              302.31501 SECONDS

"Y" PROBE POSITION:         5.550


STATISTICAL ANALYSIS

NUMBER OF SAMPLES          :   30000.
SECONDS FOR DELAY          :    0.01
MINIMUM VOLTAGE FOUND      =    0.179 VOLTS
MAXIMUM VOLTAGE FOUND      =    0.481 VOLTS
DATA IS IN MULTIPLES OF         0.005 VOLTS

  30000.-SAMPLES MEAN:       XM=      0.315
SAMPLE STANDARD DEVIATION:   SM=      0.051


THE  61 FREQUENCIES OBTAINED :

NUM   VALUE      FREQ                GRAPH ( FROM 0.0 TO 0.04 )
                                ( SCALE IS    ! =    24.7 SAMPLES )

  1   0.179   0.00033   |                                                  |
  2   0.184   0.00040   |                                                  |
  3   0.189   0.00060   |                                                  |
  4   0.194   0.00213   |!!                                                |
  5   0.199   0.00180   |!!                                                |
  6   0.204   0.00320   |!!!                                               |
  7   0.209   0.00377   |!!!!                                              |
  8   0.214   0.00667   |!!!!!!!!                                          |
  9   0.219   0.01017   |!!!!!!!!!!!!                                      |
 10   0.224   0.01117   |!!!!!!!!!!!!!                                     |
 11   0.229   0.01170   |!!!!!!!!!!!!!!                                    |
 12   0.234   0.01253   |!!!!!!!!!!!!!!!                                   |
 13   0.239   0.01733   |!!!!!!!!!!!!!!!!!!!!!                             |
 14   0.244   0.01770   |!!!!!!!!!!!!!!!!!!!!!                             |
 15   0.249   0.02060   |!!!!!!!!!!!!!!!!!!!!!!!!!                         |
 16   0.254   0.02100   |!!!!!!!!!!!!!!!!!!!!!!!!!                         |
 17   0.259   0.02537   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                    |
 18   0.264   0.02660   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                  |
 19   0.269   0.02967   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!              |
 20   0.274   0.03127   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!            |
 21   0.279   0.03087   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!             |
 22   0.284   0.03303   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
 23   0.289   0.03323   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
 24   0.294   0.03430   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!         |
 25   0.299   0.03347   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!          |
 26   0.304   0.03643   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 27   0.309   0.03690   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 28   0.314   0.04110   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!! |
 29   0.319   0.03647   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 30   0.324   0.03620   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!      |
 31   0.329   0.03437   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!         |
 32   0.334   0.03253   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!         |
```

```
 33   0.339   0.02917   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                 |
 34   0.344   0.03147   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!              |
 35   0.349   0.02993   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                |
 36   0.354   0.02940   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                 |
 37   0.359   0.02767   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                   |
 38   0.364   0.02410   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!                       |
 39   0.369   0.02383   |!!!!!!!!!!!!!!!!!!!!!!!!!!!!                        |
 40   0.374   0.01997   |!!!!!!!!!!!!!!!!!!!!!!!!                            |
 41   0.379   0.01677   |!!!!!!!!!!!!!!!!!!!!                                |
 42   0.384   0.01590   |!!!!!!!!!!!!!!!!!!!                                 |
 43   0.389   0.01327   |!!!!!!!!!!!!!!!!                                    |
 44   0.394   0.01067   |!!!!!!!!!!!!                                        |
 45   0.399   0.00910   |!!!!!!!!!!!                                         |
 46   0.404   0.00823   |!!!!!!!!!!                                          |
 47   0.409   0.00643   |!!!!!!!                                             |
 48   0.414   0.00613   |!!!!!!!                                             |
 49   0.419   0.00633   |!!!!!!!                                             |
 50   0.424   0.00493   |!!!!!!                                              |
 51   0.429   0.00383   |!!!!                                                |
 52   0.434   0.00317   |!!!                                                 |
 53   0.439   0.00220   |!!                                                  |
 54   0.444   0.00157   |!                                                   |
 55   0.449   0.00093   |!                                                   |
 56   0.454   0.00040   |                                                    |
 57   0.459   0.00013   |                                                    |
 58   0.464   0.00033   |                                                    |
 59   0.469   0.00030   |                                                    |
 60   0.474   0.00073   |                                                    |
 61   0.479   0.00020   |                                                    |
                        =======
            SUM = 1.00000

VALUES FOUND THROUGH THE CURVE OF FREQUENCIES:
               MEAN     =      0.313
STANDARD DEVIATION =      0.035
             MEDIAN    =      0.310
               MODE     =      0.314
           SKEWNESS   =      0.587
           KURTOSIS   =   -180.978

MOMENTS ABOUT THE ORIGEN AT ZERO:
                    FIRST    =    0.312957
                    SECOND   =    0.100539
                    THIRD    =    0.033108
                    FOURTH   =    0.011159
MOMENTS ABOUT THE MEAN (AND SHEPARD CORRECTIONS) :
                    FIRST    =   -0.002147
                    SECOND   =    0.001248          CORRECT.=     0.001246
                    THIRD    =    0.000641
                    FOURTH   =   -0.000251          CORRECT.=    -0.000251
COEFFICIENT BETA AND GAMMA:
                    BETA 1   =  212.411929          BETA 2   = -177.977575
                    GAMMA 1  =   14.574359          GAMMA 2  = -180.977575
```

4.10 Example of FN12 after Boundary Layer Analysis

```
================================================
===  USDA NATIONAL SEDIMENTATION LABORATORY  ===
===                   AND                    ===
===      THE UNIVERSITY OF  MISSISSIPPI      ===
================================================

================================================
===      P R O G R A M     V E L M E A S     ===
===             VERSION 1 (1986)             ===
===         MEASUREMENT AND ANALYSES         ===
===     OF VELOCITIES IN TURBULENT FLOWS     ===
================================================
```

```
A TRANSFORMATION FUNCTION HAS BEEN DEFINED BY:
     VELOCITY = A * VOLTS +  B * SQRT(VOLTS)  +  C
, WITH:  A =      0.00000 ,  B =      0.75800 , C =      0.00000 .
```

STATISTICAL PARAMETERS OBTAINED:

POS	SAMPLES	MEAN	S.D.	SKEW	KURT
1.550	30000.	0.363	0.155	0.018	-2.610
2.550	30000.	0.385	0.159	0.543	-335.087
3.550	30000.	0.400	0.166	0.618	-277.495
4.550	30000.	0.414	0.171	0.624	-267.974
5.550	30000.	0.425	0.171	0.587	-180.978
6.550	30000.	0.431	0.175	0.484	-128.700
7.550	30000.	0.442	0.176	0.464	-119.940
8.550	30000.	0.452	0.179	0.554	-229.236
9.550	30000.	0.454	0.179	0.789	-384.388
10.550	30000.	0.464	0.186	0.577	-191.162
12.550	30000.	0.474	0.186	0.678	-285.742
14.550	30000.	0.485	0.186	0.758	-358.812
16.550	30000.	0.491	0.189	0.738	-322.704
18.550	30000.	0.499	0.183	1.017	-735.631
21.550	30000.	0.511	0.181	1.298	-1583.764
25.550	30000.	0.524	0.176	1.431	-1284.574
30.550	30000.	0.538	0.175	1.614	-2497.462
35.550	30000.	0.548	0.171	2.353	-6752.655
40.550	30000.	0.564	0.169	4.180	-62807.051
45.550	30000.	0.574	0.173	3.911	-32192.001
50.550	30000.	0.583	0.161	99999.999	99999.999
55.550	30000.	0.593	0.155	99999.999	99999.999
60.550	30000.	0.600	0.153	99999.999	99999.999

VELOCITY DISTRIBUTION TREATMENT

0) POINTS ARE REARRENGED (IF NECESSARY) FROM BED TO WATER SURFACE

1) POSITION CORRECTION FOR BOTTOM PROXIMITY

```
LEVEL #   1 : COR=   0.55800 , NEW Y=     2.1C8
LEVEL #   2 : COR=   C.5563C , NEW Y=     3.106
LEVEL #   3 : COR=   C.55133 , NEW Y=     4.1C1
LEVEL #   4 : COR=   0.54333 , NEW Y=     5.C93
LEVEL #   5 : CCR=   C.53253 , NEW Y=     6.C83
LEVEL #   6 : COR=   C.51913 , NEW Y=     7.069
LEVEL #   7 : COR=   0.5C338 , NEW Y=     8.053
LEVEL #   8 : CCR=   C.48549 , NEW Y=     9.C35
LEVEL #   9 : COR=   C.4657C , NEW Y=    1C.016
LEVEL #  10 : CCR=   C.44421 , NEW Y=    10.994
LEVEL #  11 : COR=   C.39709 , NEW Y=    12.947
LEVEL #  12 : COR=   C.34591 , NEW Y=    14.896
LEVEL #  13 : COR=   C.29250 , NEW Y=    16.842
LEVEL #  14 : COR=   C.23863 , NEW Y=    18.789
LEVEL #  15 : COR=   C.16C91 , NEW Y=    21.711
LEVEL #  16 : COR=   C.07251 , NEW Y=    25.623
LEVEL #  17 : COR=   C.0C667 , NEW Y=    3C.557

2) OBTENTICN OF BEST REGRESSION

   1-ORDER REGRESSICN:       SD=      0.0063610
   2-ORDER REGRESSICN:       SD=      0.0019786
   3-ORDER REGRESSION:       SD=      C.0015837
   4-ORDER REGRESSICN:       SD=      C.CC16C34
   5-ORDER REGRESSICN:       SD=      C.0016495
   6-ORDER REGRESSICN:       SD=      C.0016576

FCR   23 POINTS, BEST REGRESSION FOUND IS OF ORDER    3
INTERCEPTICN COEFFICIENT :   A =      C.3178469
REGRESSION COEFFICIENTS  :   B =   C.6222754E-01 -0.4311474E-C2  0.1449803E-02


3) COMPUTE MAXIMUM VELOCITY IN THE REGRESSICN


MAXIMUM VELOCITY FOUND FOR SELECTED REGRESSION:
        UM=      C.60077           AT YM=     60.55CC0
                          ( LN(YM) = ZM=      4.10347 )
        MAXIMUM LEVEL ACCOUNTED   YMA =     60.55CCC


4)  VALUES OBTAINED:
```

K	Y	U	Y/YM	Z/ZM	U/UM	UR/UM	ERR%
1	2.1C8	C.363	C.035	0.182	C.6C4	0.6C3	0.076
2	3.1C6	C.385	C.051	0.276	C.641	0.641	0.017
3	4.1C1	0.400	0.068	0.344	0.666	0.668	-C.194
4	5.093	0.414	C.084	0.397	C.690	C.689	C.122
5	6.083	0.425	0.10C	0.440	C.7C8	0.7C7	0.178
6	7.069	C.431	0.117	0.477	C.717	0.722	-0.716
7	8.053	C.442	0.133	0.5C8	C.736	0.736	-C.016
8	9.035	C.452	0.149	C.536	C.753	0.748	0.64C

9	10.016	0.454	0.165	0.562	0.755	0.759	-0.557
10	10.994	0.464	0.182	0.584	0.772	0.769	0.288
11	12.947	0.474	0.214	0.624	0.789	0.788	0.148
12	14.896	0.485	0.246	0.658	0.808	0.804	0.479
13	16.842	0.491	0.278	0.688	0.818	0.819	-0.122
14	18.789	0.499	0.310	0.715	0.830	0.832	-0.217
15	21.711	0.511	0.359	0.750	0.851	0.850	0.098
16	25.623	0.524	0.423	0.790	0.871	0.872	-0.053
17	30.557	0.538	0.505	0.833	0.896	0.896	-0.013
18	35.550	0.548	0.587	0.870	0.912	0.917	-0.530
19	40.550	0.564	0.670	0.902	0.938	0.927	0.169
20	45.550	0.574	0.752	0.931	0.956	0.954	0.163
21	50.550	0.583	0.835	0.956	0.970	0.971	-0.071
22	55.550	0.593	0.917	0.979	0.988	0.986	0.207
23	60.550	0.600	1.000	1.000	0.999	1.000	-0.094

```
==========================================================================================
 TGC=        23.500 CELSIUS D.,     DEP=        2.510 INCHES
 CH =        12.000 IN.HG.     ,    SLP=    0.0012000
 BFL=         1.972 FEET


SIDE-WALL CORRECTION PARAMETERS:

CHANNEL WIDTH                    BFL=       0.601 METER
TEMPERATURE                      TGC=      23.5 CELSIUS DEG.
VISCOSITY                        VIS=       0.924E-06 SQ.METERS/SEC.
DEPTH                            DEP=       0.0638 METER
DISCHARGE MANOMETER READING      CH =       0.3048 METER (OF HG)
DISCHARGE                        CFT=       0.01760 CUB.METERS/SEC.
ENERGY SLOPE                     SLP=       0.0012000
MEAN VELOCITY                    VEL=       0.4594 METERS/SEC.
HYDRAULIC RATIO                  RAD=       0.0526 METER
SHEAR VELOCITY                   SHE=       0.0249 METER/SEC.
DARCY-WEISBACH FRICT.COEFF.      FRC=       0.0235
REYNOLDS NUMBER                  REY=       0.105E+06
REY/FRC RATIO                    RAT=       0.445E+07
WALL-FRICTION COEFF.             FRW=       0.0202
BED-FRICTION COEFF.              FRB=       0.0242
BED HYDRAULIC RATIO              RBD=       0.0541 METER
BED SHEAR VELOCITY               SHB=       0.0253 METER/SEC.
BED/GLOBAL STRESS RATIO          BST=       1.03
WALL/GLOBAL STRESS RATIO         WST=       0.66

2) DETENTION OF BEST REGRESSION

   1-ORDER REGRESSION:          SD=       0.2518716
   2-ORDER REGRESSION:          SD=       0.0783470
   3-ORDER REGRESSION:          SD=       0.0627081
   4-ORDER REGRESSION:          SD=       0.0634887
   5-ORDER REGRESSION:          SD=       0.0653132
   6-ORDER REGRESSION:          SD=       0.0656349
```

```
FOR    23 POINTS, BEST REGRESSION FOUND IS OF ORDER     3
INTERCEPTION COEFFICIENT :    A =        0.4877866
REGRESSION COEFFICIENTS  :    B =    0.5478250E+01 -0.7404486E+00  0.5740701E-01
```

NEW VALUES OBTAINED:

K	Y+	LN(Y+)	U+	UR+	ERR%
1	57.620	4.054	14.352	14.363	-0.076
2	84.907	4.442	15.243	15.245	-0.017
3	112.106	4.719	15.884	15.854	0.194
4	139.221	4.936	16.392	16.412	-0.121
5	166.260	5.114	16.816	16.845	-0.177
6	193.227	5.264	17.181	17.058	0.721
7	220.131	5.394	17.504	17.501	0.016
8	246.976	5.509	17.794	17.908	-0.635
9	273.769	5.612	18.059	17.958	0.560
10	300.515	5.705	18.302	18.355	-0.288
11	353.895	5.869	18.740	18.768	-0.148
12	407.164	6.009	19.127	19.218	-0.477
13	460.372	6.132	19.475	19.451	0.122
14	513.568	6.241	19.793	19.750	0.218
15	593.445	6.386	20.226	20.246	-0.098
16	700.365	6.552	20.740	20.729	0.053
17	835.235	6.728	21.311	21.308	0.013
18	971.722	6.879	21.821	21.706	0.533
19	1108.392	7.011	22.282	22.320	-0.168
20	1245.062	7.127	22.703	22.740	-0.163
21	1381.732	7.231	23.090	23.074	0.071
22	1518.402	7.325	23.451	23.499	-0.206
23	1655.072	7.412	23.788	23.766	0.094

2) OBTENTION OF BEST REGRESSION

```
1-ORDER REGRESSION:       SD=       0.2534934
2-ORDER REGRESSION:       SD=       0.0782671
3-ORDER REGRESSION:       SD=       0.0564429
4-ORDER REGRESSION:       SD=       0.0568672
5-ORDER REGRESSION:       SD=       0.0582289
6-ORDER REGRESSION:       SD=       0.0592834
```

```
FOR    22 POINTS, BEST REGRESSION FOUND IS OF ORDER     3
INTERCEPTION COEFFICIENT :    A =       -1.0358691
REGRESSION COEFFICIENTS  :    B =   0.6290344E+01 -0.8804411E+00  0.6526424E-01
```

```
POINT Y =     193.227 , ELIMINATED. NEW ERROR VALUES:
   -0.137     0.049     0.301    -0.006    -0.064     0.112    -0.551     0.635
   -0.223    -0.100    -0.444     0.142     0.227    -0.100     0.041    -0.005
    0.514    -0.184    -0.173     0.069    -0.199    -0.111
```

2) OBTENTION OF BEST REGRESSION

```
   1-ORDER REGRESSION:        SD=      0.2497567
   2-ORDER REGRESSION:        SD=      0.0772329
   3-ORDER REGRESSION:        SD=      0.0501894
   4-ORDER REGRESSION:        SD=      0.0482899
   5-ORDER REGRESSION:        SD=      0.0483371
   6-ORDER REGRESSION:        SD=      0.0470749

 FOR   21 POINTS, BEST REGRESSION FOUND IS OF ORDER    6
 INTERCEPTION COEFFICIENT :   A =   -839.2258683
 REGRESSION COEFFICIENTS  :   B =  0.9435844E+03 -0.4327312E+03  0.1050031E+03
                                  -0.1418576E+02  0.1011758E+01 -0.2975350E-01


 POINT Y =     273.769 , ELIMINATED. NEW ERROR VALUES:
     0.002    -0.031     0.116    -0.115    -0.051     0.316    -0.301     0.044
     0.119    -0.301     0.205     0.218    -0.192    -0.105    -0.141     0.439
    -0.181    -0.108     0.156    -0.146     0.062

   2 POINTS ELIMINATED FROM    23 ORIGINAL POINTS. <<==

================================================================================
 FLOW RESISTANCE CALCULATIONS FROM REGRESSION
  MEAN VELOCITY            UA   =        0.520 M./SEC.
  DIMENSIONLESS MEAN       UA+ =        20.577
  DARCY-WEISBACH COEFF.     F   =        0.019
                   1./SQRT(F)  =        7.275


          *****************************************
          ***                                   ***
          ***         CASE NUMBER 19            ***
          ***                                   ***
          *****************************************


 VALUES BEFORE ORIGIN CORRECTION FOR THE CASE NUMBER 19
 LAW-OF-THE-WALL COORDINATES Y+ AND U+
 (LAST VALUE CORRESPONDS TO THE DEPTH )
```

I	Y+	LN(Y+)	U+
1	57.620	4.054	14.363
2	84.907	4.442	15.245
3	112.106	4.719	15.854
4	139.221	4.936	16.412
5	166.260	5.114	16.845
6	220.131	5.394	17.501
7	246.976	5.509	17.908
8	300.515	5.705	18.355
9	353.895	5.869	18.768
10	407.164	6.009	19.218
11	460.372	6.132	19.451
12	513.568	6.241	19.750
13	593.445	6.386	20.246
14	700.365	6.552	20.729
15	835.235	6.728	21.308
16	971.722	6.879	21.706

17	1108.392	7.011	22.320
18	1245.062	7.127	22.740
19	1381.732	7.231	23.074
20	1518.402	7.325	23.499
21	1655.072	7.412	23.766
SURFACE	1742.650	7.463	23.963

SURFACE VALUES HAS BEEN ADDED TO Y+,U+ LAW AS THE POINT NUMBER 22
BOUNDARY LAYER THICKNESS D+ = 1742.650 (IN Y+ COORD.)
REFERENCE FLOW VELOCITY VM+ = 23.963 (IN U+ COORD.)

LAW TYPE 1 : LN(Y+)
USING 4 POINTS (PER = 8.00 % OF B.LAYER)
STANDARD ERROR OF ESTIMATE SE = 0.230E-01
2ND.-ORDER REGR.COEFF. B(2)= -0.287E-06
VIRTUAL ORIGIN DISTANCE EPS = 0.00061 (IN METERS)
VIRTUAL ORIGIN DISTANCE EP+ = 16.637 (IN Y+ COORD.)
INTERCEPT AP = 2.548 (IN U+ COORD.)
KARMAN COEFFICIENT VK = 0.364
WAKE STRENGTH PI = 0.166
BOUNDARY LAYER THICKNESS D+ = 1759.287 (IN Y+ COORD.)
REFERENCE FLOW VELOCITY VM+ = 23.963 (IN U+ COORD.)

LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	74.257	4.308	14.363	0.042	-3.165	9.600	-0.010	0.009	0.099
2	101.545	4.620	15.245	0.058	-2.852	8.718	0.041	0.016	0.139
3	128.743	4.858	15.854	0.073	-2.615	8.110	-0.053	0.026	0.180
4	155.858	5.049	16.412	0.089	-2.424	7.551	0.022	0.038	0.222
5	182.897	5.209	16.845	0.104	-2.264	7.118	0.009	0.053	0.265
6	236.768	5.467	17.501	0.135	-2.006	6.462	-0.106	0.088	0.355
7	263.613	5.574	17.908	0.150	-1.898	6.055	0.141	0.109	0.401
8	317.153	5.759	18.355	0.180	-1.713	5.608	0.008	0.156	0.496
9	370.533	5.915	18.768	0.211	-1.558	5.195	-0.023	0.211	0.594
10	423.802	6.049	19.218	0.241	-1.423	4.745	0.157	0.273	0.694
11	477.010	6.168	19.451	0.271	-1.305	4.512	-0.044	0.341	0.796
12	530.205	6.273	19.750	0.301	-1.199	4.213	-0.025	0.416	0.898
13	610.083	6.414	20.246	0.347	-1.059	3.718	0.217	0.537	1.052
14	717.002	6.575	20.729	0.408	-0.898	3.234	0.306	0.714	1.256
15	851.872	6.747	21.308	0.484	-0.725	2.655	0.536	0.950	1.501
16	988.360	6.896	21.706	0.562	-0.577	2.257	0.517	1.193	1.725
17	1125.030	7.026	22.320	0.639	-0.447	1.643	1.085	1.424	1.914
18	1261.700	7.140	22.740	0.717	-0.332	1.224	1.316	1.631	2.056
19	1398.369	7.243	23.074	0.795	-0.230	0.889	1.430	1.799	2.140
20	1535.039	7.336	23.499	0.873	-0.136	0.464	1.803	1.921	2.155
21	1671.709	7.422	23.766	0.950	-0.051	0.197	1.875	1.988	2.090
22	1759.287	7.473	23.963	1.000	0.000	0.000	2.000	2.000	2.000

LAW TYPE 1 : LN(Y+)
USING 5 POINTS (PER = 10.00 % OF B.LAYER)
STANDARD ERROR OF ESTIMATE SE = 0.188E-01
2ND.-ORDER REGR.COEFF. B(2)= 0.934E-06
VIRTUAL ORIGIN DISTANCE EPS = 0.00065 (IN METERS)

```
VIRTUAL ORIGIN DISTANCE      EP+ =      17.674 ( IN Y+ COORD.)
INTERCEPT                    AP  =       2.386 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK  =       0.361
WAKE STRENGTH                PI  =       0.154
BOUNDARY LAYER THICKNESS     D+  =    1760.324 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+ =      23.963 ( IN U+ COORD.)
```

LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	75.294	4.321	14.363	0.043	-3.152	9.600	-0.012	0.009	0.106
2	102.582	4.631	15.245	0.058	-2.843	8.718	0.046	0.017	0.148
3	129.780	4.866	15.854	0.074	-2.607	8.110	-0.056	0.027	0.191
4	156.895	5.056	16.412	0.089	-2.418	7.551	0.019	0.039	0.234
5	183.934	5.215	16.845	0.104	-2.259	7.118	0.002	0.053	0.280
6	237.805	5.471	17.501	0.135	-2.002	6.462	-0.130	0.089	0.373
7	264.650	5.578	17.908	0.150	-1.895	6.055	0.128	0.109	0.420
8	318.190	5.763	18.355	0.181	-1.711	5.608	-0.021	0.157	0.518
9	371.569	5.918	18.768	0.211	-1.556	5.195	-0.061	0.212	0.619
10	424.839	6.052	19.218	0.241	-1.422	4.745	0.123	0.274	0.721
11	478.046	6.170	19.451	0.272	-1.304	4.512	-0.097	0.342	0.825
12	531.242	6.275	19.750	0.302	-1.198	4.213	-0.082	0.417	0.929
13	611.120	6.415	20.246	0.347	-1.058	3.718	0.168	0.538	1.085
14	718.039	6.577	20.729	0.408	-0.897	3.234	0.254	0.715	1.291
15	852.909	6.749	21.308	0.485	-0.725	2.655	0.490	0.951	1.537
16	989.397	6.897	21.706	0.562	-0.576	2.257	0.459	1.194	1.760
17	1126.067	7.026	22.320	0.640	-0.447	1.643	1.054	1.425	1.947
18	1262.736	7.141	22.740	0.717	-0.332	1.224	1.293	1.631	2.085
19	1399.406	7.244	23.074	0.795	-0.229	0.889	1.409	1.800	2.163
20	1536.076	7.337	23.499	0.873	-0.136	0.464	1.799	1.921	2.171
21	1672.746	7.422	23.766	0.950	-0.051	0.197	1.870	1.988	2.096
22	1760.324	7.473	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING   6 POINTS ( PER =   13.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE  =   0.201E-01
2ND.-ORDER REGR.COEFF.       B(2)=   0.771E-06
VIRTUAL ORIGIN DISTANCE      EPS =     0.00034 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+ =       9.213 ( IN Y+ COORD.)
INTERCEPT                    AP  =       3.630 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK  =       0.392
WAKE STRENGTH                PI  =       0.247
BOUNDARY LAYER THICKNESS     D+  =    1751.862 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+ =      23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	66.833	4.202	14.363	0.038	-3.266	9.600	0.002	0.007	0.067
2	94.120	4.545	15.245	0.054	-2.924	8.718	0.014	0.014	0.097
3	121.318	4.798	15.854	0.069	-2.670	8.110	-0.049	0.024	0.130
4	148.434	5.000	16.412	0.085	-2.468	7.551	0.019	0.035	0.164
5	175.472	5.167	16.845	0.100	-2.301	7.118	0.029	0.049	0.199
6	229.343	5.435	17.501	0.131	-2.033	6.462	-0.016	0.083	0.275
7	256.188	5.546	17.908	0.146	-1.923	6.055	0.182	0.104	0.314
8	309.728	5.736	18.355	0.177	-1.733	5.608	0.122	0.150	0.397

9	363.108	5.895	18.768	0.207	-1.574	5.195	0.133	0.205	0.483
10	416.377	6.032	19.218	0.238	-1.437	4.745	0.293	0.266	0.573
11	469.585	6.152	19.451	0.268	-1.317	4.512	0.175	0.334	0.666
12	522.780	6.259	19.750	0.298	-1.209	4.213	0.214	0.408	0.760
13	602.658	6.401	20.246	0.344	-1.067	3.718	0.424	0.529	0.906
14	709.577	6.565	20.729	0.405	-0.904	3.234	0.530	0.706	1.101
15	844.447	6.739	21.308	0.482	-0.730	2.655	0.743	0.944	1.343
16	980.935	6.889	21.706	0.560	-0.580	2.257	0.767	1.187	1.570
17	1117.605	7.019	22.320	0.638	-0.449	1.643	1.213	1.420	1.770
18	1254.275	7.134	22.740	0.716	-0.334	1.224	1.412	1.628	1.931
19	1390.945	7.236	23.074	0.794	-0.231	0.889	1.523	1.798	2.040
20	1527.614	7.331	23.499	0.872	-0.137	0.464	1.819	1.920	2.087
21	1664.284	7.417	23.766	0.950	-0.051	0.197	1.895	1.988	2.061
22	1751.862	7.468	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING   7 POINTS ( PER =   15.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE   =   0.374E-01
2ND.-ORDER REGR.COEFF.       B(2)=   0.911E-06
VIRTUAL ORIGIN DISTANCE      EPS =      0.00079 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+ =       21.482 ( IN Y+ COORD.)
INTERCEPT                    AP  =        1.897 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK  =        0.350
WAKE STRENGTH                PI  =        0.127
BOUNDARY LAYER THICKNESS     D+  =     1764.131 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+ =       23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	79.102	4.371	14.363	0.045	-3.105	9.600	-0.031	0.010	0.130
2	106.389	4.667	15.245	0.060	-2.808	8.718	0.069	0.018	0.177
3	133.587	4.895	15.854	0.076	-2.581	8.110	-0.046	0.028	0.225
4	160.703	5.080	16.412	0.091	-2.396	7.551	0.039	0.041	0.275
5	187.741	5.235	16.845	0.106	-2.240	7.118	0.010	0.055	0.325
6	241.613	5.487	17.501	0.137	-1.988	6.462	-0.167	0.091	0.428
7	268.458	5.593	17.908	0.152	-1.883	6.055	0.126	0.112	0.480
8	321.997	5.775	18.355	0.183	-1.701	5.608	-0.073	0.160	0.587
9	375.377	5.928	18.768	0.213	-1.547	5.195	-0.142	0.215	0.695
10	428.646	6.061	19.218	0.243	-1.415	4.745	0.055	0.277	0.804
11	481.854	6.178	19.451	0.273	-1.298	4.512	-0.223	0.346	0.913
12	535.049	6.282	19.750	0.303	-1.193	4.213	-0.224	0.421	1.022
13	614.927	6.422	20.246	0.349	-1.054	3.718	0.047	0.542	1.185
14	721.846	6.582	20.729	0.409	-0.894	3.234	0.119	0.719	1.396
15	856.717	6.753	21.308	0.486	-0.722	2.655	0.366	0.955	1.645
16	993.204	6.901	21.706	0.563	-0.574	2.257	0.299	1.197	1.866
17	1129.874	7.030	22.320	0.640	-0.446	1.643	0.976	1.427	2.045
18	1266.544	7.144	22.740	0.718	-0.331	1.224	1.235	1.632	2.170
19	1403.214	7.247	23.074	0.795	-0.229	0.889	1.350	1.800	2.231
20	1539.884	7.339	23.499	0.873	-0.136	0.464	1.791	1.921	2.217
21	1676.553	7.424	23.766	0.950	-0.051	0.197	1.858	1.988	2.116
22	1764.131	7.475	23.963	1.000	0.000	0.000	2.000	2.000	2.000

LAW TYPE 1 : LN(Y+)

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USING    8 POINTS ( PER =    18.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE   =     0.347E-01
2ND.-ORDER REGR.COEFF.       B(2)=   -0.307E-06
VIRTUAL ORIGIN DISTANCE      EPS  =      0.00069 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+  =       18.740 ( IN Y+ COORD.)
INTERCEPT                    AP   =        2.263 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK   =        0.358
WAKE STRENGTH                PI   =        0.148
BOUNDARY LAYER THICKNESS     D+   =     1761.390 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+  =       23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	76.360	4.335	14.363	0.043	-3.138	9.600	-0.018	0.009	0.111
2	103.648	4.641	15.245	0.059	-2.833	8.718	0.052	0.017	0.154
3	130.846	4.874	15.854	0.074	-2.600	8.110	-0.050	0.027	0.198
4	157.961	5.062	16.412	0.090	-2.412	7.551	0.028	0.039	0.243
5	185.000	5.220	16.845	0.105	-2.254	7.118	0.009	0.054	0.289
6	238.871	5.476	17.501	0.136	-1.998	6.462	-0.131	0.089	0.383
7	265.716	5.582	17.908	0.151	-1.891	6.055	0.134	0.110	0.432
8	319.256	5.766	18.355	0.181	-1.708	5.608	-0.024	0.158	0.532
9	372.636	5.921	18.768	0.212	-1.553	5.195	-0.071	0.213	0.633
10	425.905	6.054	19.218	0.242	-1.420	4.745	0.116	0.275	0.737
11	479.113	6.172	19.451	0.272	-1.302	4.512	-0.115	0.343	0.842
12	532.308	6.277	19.750	0.302	-1.197	4.213	-0.104	0.418	0.947
13	612.186	6.417	20.246	0.348	-1.057	3.718	0.150	0.539	1.104
14	719.105	6.578	20.729	0.408	-0.896	3.234	0.232	0.716	1.311
15	853.975	6.750	21.308	0.485	-0.724	2.655	0.470	0.952	1.558
16	990.463	6.898	21.706	0.562	-0.576	2.257	0.431	1.195	1.780
17	1127.133	7.027	22.320	0.640	-0.446	1.643	1.042	1.426	1.965
18	1263.802	7.142	22.740	0.718	-0.332	1.224	1.284	1.631	2.101
19	1400.472	7.245	23.074	0.795	-0.229	0.889	1.399	1.800	2.176
20	1537.142	7.338	23.499	0.873	-0.136	0.464	1.798	1.921	2.179
21	1673.812	7.423	23.766	0.950	-0.051	0.197	1.868	1.988	2.100
22	1761.390	7.474	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING    9 POINTS ( PER =    21.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE   =     0.329E-01
2ND.-ORDER REGR.COEFF.       B(2)=   -0.581E-06
VIRTUAL ORIGIN DISTANCE      EPS  =      0.00060 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+  =       16.353 ( IN Y+ COORD.)
INTERCEPT                    AP   =        2.567 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK   =        0.365
WAKE STRENGTH                PI   =        0.166
BOUNDARY LAYER THICKNESS     D+   =     1759.003 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+  =       23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	73.973	4.304	14.363	0.042	-3.169	9.600	-0.006	0.009	0.099
2	101.261	4.618	15.245	0.058	-2.855	8.718	0.041	0.016	0.138
3	128.459	4.856	15.854	0.073	-2.617	8.110	-0.055	0.026	0.179
4	155.574	5.047	16.412	0.088	-2.425	7.551	0.018	0.038	0.221

5	182.613	5.207	16.845	0.104	-2.265	7.118	0.005	0.053	0.265
6	236.484	5.466	17.501	0.134	-2.007	6.462	-0.112	0.088	0.354
7	263.329	5.573	17.908	0.150	-1.899	6.055	0.135	0.109	0.401
8	316.869	5.758	18.355	0.180	-1.714	5.608	0.003	0.156	0.496
9	370.249	5.914	18.768	0.210	-1.558	5.195	-0.029	0.211	0.594
10	423.518	6.049	19.218	0.241	-1.424	4.745	0.152	0.273	0.694
11	476.726	6.167	19.451	0.271	-1.306	4.512	-0.049	0.341	0.795
12	529.921	6.273	19.750	0.301	-1.200	4.213	-0.030	0.415	0.898
13	609.799	6.413	20.246	0.347	-1.059	3.718	0.213	0.537	1.052
14	716.718	6.575	20.729	0.407	-0.898	3.234	0.303	0.713	1.256
15	851.588	6.747	21.308	0.484	-0.725	2.655	0.535	0.950	1.501
16	988.076	6.896	21.706	0.562	-0.577	2.257	0.514	1.193	1.725
17	1124.746	7.025	22.320	0.639	-0.447	1.643	1.083	1.424	1.914
18	1261.415	7.140	22.740	0.717	-0.333	1.224	1.314	1.630	2.056
19	1398.085	7.243	23.074	0.795	-0.230	0.889	1.429	1.799	2.140
20	1534.755	7.336	23.499	0.873	-0.136	0.464	1.802	1.921	2.155
21	1671.425	7.421	23.766	0.950	-0.051	0.197	1.875	1.988	2.090
22	1759.003	7.473	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  10 POINTS ( PER =   24.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE    SE   =   0.356E-01
2ND.-ORDER REGR.COEFF.        B(2)=    0.250E-07
VIRTUAL ORIGIN DISTANCE       EPS  =      0.00077 ( IN METERS )
VIRTUAL ORIGIN DISTANCE       EP+  =       21.118 ( IN Y+ COORD.)
INTERCEPT                     AP   =        1.984 ( IN U+ COORD.)
KARMAN COEFFICIENT            VK   =        0.352
WAKE STRENGTH                 PI   =        0.134
BOUNDARY LAYER THICKNESS      D+   =     1763.768 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY       VP+  =       23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UP-U+	WAKE	COLES	FINLEY
1	78.738	4.366	14.363	0.045	-3.109	9.600	-0.036	0.010	0.124
2	106.025	4.664	15.245	0.060	-2.812	8.718	0.063	0.018	0.169
3	133.224	4.892	15.854	0.076	-2.583	8.110	-0.041	0.028	0.216
4	160.339	5.077	16.412	0.091	-2.398	7.551	0.044	0.041	0.263
5	187.378	5.233	16.845	0.106	-2.242	7.118	0.021	0.055	0.312
6	241.249	5.486	17.501	0.137	-1.989	6.462	-0.141	0.091	0.412
7	268.094	5.591	17.908	0.152	-1.884	6.055	0.142	0.112	0.463
8	321.633	5.773	18.355	0.182	-1.702	5.608	-0.041	0.160	0.567
9	375.013	5.927	18.768	0.213	-1.548	5.195	-0.102	0.215	0.672
10	428.282	6.060	19.218	0.243	-1.415	4.745	0.091	0.277	0.779
11	481.490	6.177	19.451	0.273	-1.298	4.512	-0.170	0.346	0.887
12	534.686	6.282	19.750	0.303	-1.194	4.213	-0.166	0.420	0.994
13	614.563	6.421	20.246	0.348	-1.054	3.718	0.097	0.542	1.155
14	721.483	6.581	20.729	0.409	-0.894	3.234	0.172	0.718	1.365
15	856.353	6.753	21.308	0.486	-0.723	2.655	0.414	0.955	1.612
16	992.841	6.901	21.706	0.563	-0.575	2.257	0.356	1.196	1.833
17	1129.510	7.030	22.320	0.640	-0.446	1.643	1.007	1.427	2.014
18	1266.180	7.144	22.740	0.718	-0.331	1.224	1.258	1.632	2.144
19	1402.850	7.246	23.074	0.795	-0.229	0.869	1.371	1.800	2.210
20	1539.520	7.339	23.499	0.873	-0.136	0.464	1.796	1.921	2.202
21	1676.190	7.424	23.766	0.950	-0.051	0.197	1.862	1.988	2.110

22	1763.768	7.475	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  11 POINTS ( PER =   27.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE  =   0.371E-01
2ND.-ORDER REGR.COEFF.       B(2)=   0.547E-06
VIRTUAL ORIGIN DISTANCE      EPS =     0.00063 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+ =      17.304 ( IN Y+ COORD.)
INTERCEPT                    AP  =       2.434 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK  =       0.362
WAKE STRENGTH                PI  =       0.157
BOUNDARY LAYER THICKNESS     D+  =    1759.954 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+ =      23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	74.924	4.316	14.363	0.043	-3.157	9.600	-0.008	0.009	0.104
2	102.212	4.627	15.245	0.058	-2.846	8.718	0.046	0.017	0.145
3	129.410	4.863	15.854	0.074	-2.610	8.110	-0.054	0.027	0.187
4	156.525	5.053	16.412	0.089	-2.420	7.551	0.020	0.039	0.231
5	183.564	5.213	16.845	0.104	-2.260	7.118	0.004	0.053	0.275
6	237.435	5.470	17.501	0.135	-2.003	6.462	-0.124	0.088	0.367
7	264.280	5.577	17.908	0.150	-1.896	6.055	0.131	0.109	0.415
8	317.820	5.761	18.355	0.181	-1.712	5.608	-0.013	0.157	0.512
9	371.200	5.917	18.768	0.211	-1.556	5.195	-0.051	0.212	0.612
10	424.469	6.051	19.218	0.241	-1.422	4.745	0.132	0.274	0.713
11	477.677	6.169	19.451	0.271	-1.304	4.512	-0.083	0.342	0.816
12	530.872	6.275	19.750	0.302	-1.199	4.213	-0.067	0.416	0.920
13	610.750	6.415	20.246	0.347	-1.058	3.718	0.181	0.538	1.076
14	717.669	6.576	20.729	0.408	-0.897	3.234	0.268	0.714	1.281
15	852.539	6.748	21.308	0.484	-0.725	2.655	0.503	0.951	1.527
16	989.027	6.897	21.706	0.562	-0.576	2.257	0.474	1.193	1.750
17	1125.697	7.026	22.320	0.640	-0.447	1.643	1.063	1.425	1.937
18	1262.367	7.141	22.740	0.717	-0.332	1.224	1.299	1.631	2.077
19	1399.036	7.244	23.074	0.795	-0.230	0.889	1.414	1.800	2.157
20	1535.706	7.337	23.499	0.873	-0.136	0.464	1.800	1.921	2.166
21	1672.376	7.422	23.766	0.950	-0.051	0.197	1.872	1.988	2.094
22	1759.954	7.473	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  12 POINTS ( PER =   30.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE  =   0.360E-01
2ND.-ORDER REGR.COEFF.       B(2)=   0.362E-06
VIRTUAL ORIGIN DISTANCE      EPS =     0.00058 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+ =      15.877 ( IN Y+ COORD.)
INTERCEPT                    AP  =       2.598 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK  =       0.365
WAKE STRENGTH                PI  =       0.166
BOUNDARY LAYER THICKNESS     D+  =    1758.526 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+ =      23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY

1	73.497	4.297	14.363	0.042	-3.175	9.600	0.002	0.009	0.098
2	100.784	4.613	15.245	0.057	-2.859	8.718	0.041	0.016	0.138
3	127.983	4.852	15.854	0.073	-2.620	8.110	-0.059	0.026	0.179
4	155.098	5.044	16.412	0.088	-2.428	7.551	0.012	0.038	0.221
5	182.136	5.205	16.845	0.104	-2.267	7.118	-0.002	0.052	0.264
6	236.008	5.464	17.501	0.134	-2.008	6.462	-0.120	0.088	0.354
7	262.853	5.572	17.908	0.149	-1.901	6.055	0.126	0.108	0.400
8	316.392	5.757	18.355	0.180	-1.715	5.608	-0.007	0.156	0.496
9	369.772	5.913	18.768	0.210	-1.559	5.195	-0.038	0.210	0.593
10	423.041	6.047	19.218	0.241	-1.425	4.745	0.143	0.272	0.693
11	476.249	6.166	19.451	0.271	-1.306	4.512	-0.058	0.341	0.795
12	529.445	6.272	19.750	0.301	-1.200	4.213	-0.039	0.415	0.898
13	609.322	6.412	20.246	0.346	-1.060	3.718	0.205	0.536	1.052
14	716.242	6.574	20.729	0.407	-0.898	3.234	0.295	0.713	1.256
15	851.112	6.747	21.308	0.484	-0.726	2.655	0.529	0.950	1.501
16	987.599	6.895	21.706	0.562	-0.577	2.257	0.509	1.192	1.726
17	1124.269	7.025	22.320	0.639	-0.447	1.643	1.079	1.424	1.914
18	1260.939	7.140	22.740	0.717	-0.333	1.224	1.311	1.630	2.057
19	1397.609	7.243	23.074	0.795	-0.230	0.889	1.427	1.799	2.141
20	1534.279	7.336	23.499	0.872	-0.136	0.464	1.801	1.921	2.155
21	1670.948	7.421	23.766	0.950	-0.051	0.197	1.874	1.988	2.090
22	1758.526	7.472	23.963	1.000	0.000	0.000	2.000	2.000	2.000

LAW TYPE 1 : LN(Y+)
USING 13 POINTS (PER = 35.00 % OF B.LAYER)

STANDARD ERROR OF ESTIMATE	SE	=	0.408E-01
2ND.-ORDER REGR.COEFF.	B(2)	=	0.674E-06
VIRTUAL ORIGIN DISTANCE	EPS	=	0.00074 (IN METERS)
VIRTUAL ORIGIN DISTANCE	EP+	=	20.339 (IN Y+ COORD.)
INTERCEPT	AP	=	2.110 (IN U+ COORD.)
KARMAN COEFFICIENT	VK	=	0.355
WAKE STRENGTH	PI	=	0.142
BOUNDARY LAYER THICKNESS	D+	=	1762.988 (IN Y+ COORD.)
REFERENCE FLOW VELOCITY	VM+	=	23.963 (IN U+ COORD.)

LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	77.959	4.356	14.363	0.044	-3.119	9.600	-0.037	0.010	0.117
2	105.246	4.656	15.245	0.060	-2.818	8.718	0.055	0.018	0.160
3	132.444	4.886	15.854	0.075	-2.589	8.110	-0.042	0.028	0.205
4	159.560	5.072	16.412	0.091	-2.402	7.551	0.042	0.040	0.251
5	186.598	5.229	16.845	0.106	-2.246	7.118	0.024	0.055	0.298
6	240.470	5.483	17.501	0.136	-1.992	6.462	-0.123	0.090	0.395
7	267.315	5.588	17.908	0.152	-1.886	6.055	0.149	0.111	0.445
8	320.854	5.771	18.355	0.182	-1.704	5.608	-0.018	0.159	0.546
9	374.234	5.925	18.768	0.212	-1.550	5.195	-0.070	0.214	0.649
10	427.503	6.058	19.218	0.242	-1.417	4.745	0.119	0.276	0.754
11	480.711	6.175	19.451	0.273	-1.299	4.512	-0.124	0.345	0.859
12	533.906	6.280	19.750	0.303	-1.195	4.213	-0.116	0.419	0.965
13	613.784	6.420	20.246	0.348	-1.055	3.718	0.140	0.541	1.124
14	720.704	6.580	20.729	0.409	-0.895	3.234	0.219	0.717	1.332
15	855.574	6.752	21.308	0.485	-0.723	2.655	0.457	0.954	1.579
16	992.061	6.900	21.706	0.563	-0.575	2.257	0.410	1.196	1.601
17	1128.731	7.029	22.320	0.640	-0.446	1.643	1.034	1.426	1.984

18	1265.401	7.143	22.740	0.718	-0.332	1.224	1.278	1.632	2.117
19	1402.071	7.246	23.074	0.795	-0.229	0.889	1.391	1.800	2.189
20	1538.741	7.339	23.499	0.873	-0.136	0.464	1.799	1.921	2.188
21	1675.410	7.424	23.766	0.950	-0.051	0.197	1.867	1.988	2.103
22	1762.988	7.475	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  14 POINTS ( PER =   41.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE   =   0.444E-01
2ND.-ORDER REGR.COEFF.       B(2)=    0.809E-06
VIRTUAL ORIGIN DISTANCE      EPS  =     0.00090 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+  =      24.628 ( IN Y+ COORD.)
INTERCEPT                    AP   =       1.664 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK   =       0.346
WAKE STRENGTH                PI   =       0.124
BOUNDARY LAYER THICKNESS     D+   =    1767.278 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+  =      23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	82.248	4.410	14.363	0.047	-3.067	9.600	-0.068	0.011	0.137
2	109.535	4.696	15.245	0.062	-2.781	8.718	0.067	0.019	0.185
3	136.734	4.918	15.854	0.077	-2.559	8.110	-0.023	0.029	0.234
4	163.849	5.099	16.412	0.093	-2.378	7.551	0.078	0.042	0.284
5	190.868	5.252	16.845	0.108	-2.226	7.118	0.057	0.057	0.335
6	244.759	5.500	17.501	0.138	-1.977	6.462	-0.117	0.093	0.439
7	271.604	5.604	17.908	0.154	-1.873	6.055	0.182	0.114	0.492
8	325.143	5.784	18.355	0.184	-1.693	5.608	-0.020	0.162	0.599
9	378.523	5.936	18.768	0.214	-1.541	5.195	-0.094	0.218	0.708
10	431.792	6.068	19.218	0.244	-1.409	4.745	0.104	0.280	0.817
11	485.000	6.184	19.451	0.274	-1.293	4.512	-0.184	0.349	0.927
12	538.196	6.288	19.750	0.305	-1.189	4.213	-0.189	0.424	1.037
13	618.073	6.427	20.246	0.350	-1.051	3.718	0.081	0.545	1.200
14	724.993	6.586	20.729	0.410	-0.891	3.234	0.145	0.722	1.412
15	859.863	6.757	21.308	0.487	-0.720	2.655	0.387	0.958	1.660
16	996.350	6.904	21.706	0.564	-0.573	2.257	0.310	1.199	1.880
17	1133.020	7.033	22.320	0.641	-0.445	1.643	0.990	1.429	2.057
18	1269.690	7.147	22.740	0.718	-0.331	1.224	1.246	1.634	2.181
19	1406.360	7.249	23.074	0.796	-0.228	0.889	1.356	1.801	2.239
20	1543.030	7.342	23.499	0.873	-0.136	0.464	1.798	1.922	2.222
21	1679.700	7.426	23.766	0.950	-0.051	0.197	1.859	1.986	2.118
22	1767.278	7.477	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  15 POINTS ( PER =   48.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE   =   0.537E-01
2ND.-ORDER REGR.COEFF.       B(2)=    0.991E-06
VIRTUAL ORIGIN DISTANCE      EPS  =     0.00115 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+  =      31.374 ( IN Y+ COORD.)
INTERCEPT                    AP   =       1.000 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK   =       0.334
WAKE STRENGTH                PI   =       0.099
BOUNDARY LAYER THICKNESS     D+   =    1774.024 ( IN Y+ COORD.)
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REFERENCE FLOW VELOCITY       VM+ =        23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	88.994	4.489	14.363	0.050	-2.992	9.600	-0.198	0.012	0.175
2	116.282	4.756	15.245	0.066	-2.725	8.718	0.080	0.021	0.231
3	143.480	4.966	15.854	0.081	-2.515	8.110	0.012	0.032	0.288
4	170.595	5.139	16.412	0.096	-2.342	7.551	0.150	0.045	0.345
5	197.634	5.286	16.845	0.111	-2.195	7.118	0.127	0.061	0.403
6	251.505	5.527	17.501	0.142	-1.954	6.462	-0.092	0.098	0.520
7	278.350	5.629	17.908	0.157	-1.852	6.055	0.258	0.119	0.578
8	331.890	5.805	18.355	0.187	-1.676	5.608	-0.008	0.168	0.697
9	385.270	5.954	18.768	0.217	-1.527	5.195	-0.121	0.224	0.815
10	438.539	6.083	19.218	0.247	-1.398	4.745	0.093	0.287	0.934
11	491.747	6.198	19.451	0.277	-1.283	4.512	-0.277	0.356	1.051
12	544.942	6.301	19.750	0.307	-1.180	4.213	-0.305	0.431	1.166
13	624.820	6.437	20.246	0.352	-1.044	3.718	-0.013	0.552	1.339
14	731.739	6.595	20.729	0.412	-0.886	3.234	0.025	0.728	1.557
15	866.609	6.765	21.308	0.486	-0.716	2.655	0.270	0.964	1.808
16	1003.097	6.911	21.706	0.565	-0.570	2.257	0.137	1.204	2.024
17	1139.767	7.039	22.320	0.642	-0.442	1.643	0.919	1.433	2.190
18	1276.436	7.152	22.740	0.720	-0.329	1.224	1.193	1.636	2.297
19	1413.106	7.254	23.074	0.797	-0.227	0.889	1.295	1.803	2.332
20	1549.776	7.346	23.499	0.874	-0.135	0.464	1.799	1.922	2.285
21	1686.446	7.430	23.766	0.951	-0.051	0.197	1.846	1.988	2.144
22	1774.024	7.481	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  16 POINTS ( PER =    56.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE   SE   =   0.531E-01
2ND.-ORDER REGR.COEFF.       B(2)=  -0.748E-06
VIRTUAL ORIGIN DISTANCE      EPS =      0.00122 ( IN METERS )
VIRTUAL ORIGIN DISTANCE      EP+ =       33.216 ( IN Y+ COORD.)
INTERCEPT                    AP  =        0.826 ( IN U+ COORD.)
KARMAN COEFFICIENT           VK  =        0.331
WAKE STRENGTH                PI  =        0.093
BOUNDARY LAYER THICKNESS     D+  =     1775.865 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY      VM+ =       23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	90.836	4.509	14.363	0.051	-2.973	9.600	-0.236	0.013	0.187
2	118.123	4.772	15.245	0.067	-2.710	8.718	0.082	0.022	0.246
3	145.322	4.979	15.854	0.082	-2.503	8.110	0.022	0.033	0.304
4	172.437	5.150	16.412	0.097	-2.332	7.551	0.172	0.046	0.364
5	199.475	5.296	16.845	0.112	-2.186	7.118	0.151	0.062	0.424
6	253.347	5.535	17.501	0.143	-1.947	6.462	-0.082	0.099	0.544
7	280.192	5.635	17.908	0.158	-1.847	6.055	0.284	0.120	0.605
8	333.731	5.810	18.355	0.188	-1.672	5.608	-0.001	0.169	0.726
9	387.111	5.959	18.768	0.218	-1.523	5.195	-0.125	0.225	0.848
10	440.380	6.088	19.218	0.248	-1.394	4.745	0.093	0.288	0.969
11	493.588	6.202	19.451	0.278	-1.280	4.512	-0.301	0.358	1.089
12	546.784	6.304	19.750	0.308	-1.178	4.213	-0.337	0.432	1.208
13	626.661	6.440	20.246	0.353	-1.042	3.718	-0.038	0.554	1.381

14	733.581	6.598	20.729	0.413	-0.884	3.234	-0.009	0.730	1.601
15	868.451	6.767	21.308	0.489	-0.715	2.655	0.237	0.966	1.853
16	1004.938	6.913	21.706	0.566	-0.569	2.257	0.087	1.206	2.068
17	1141.608	7.040	22.320	0.643	-0.442	1.643	0.899	1.434	2.231
18	1278.278	7.153	22.740	0.720	-0.329	1.224	1.178	1.637	2.332
19	1414.948	7.255	23.074	0.797	-0.227	0.889	1.277	1.803	2.360
20	1551.618	7.347	23.499	0.874	-0.135	0.464	1.799	1.922	2.304
21	1688.287	7.431	23.766	0.951	-0.051	0.197	1.843	1.988	2.152
22	1775.865	7.482	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  17 POINTS ( PER =   64.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE  SE   =   0.772E-01
2ND.-ORDER REGR.COEFF.      B(2)=   0.883E-06
VIRTUAL ORIGIN DISTANCE     EPS =      0.00161 ( IN METERS )
VIRTUAL ORIGIN DISTANCE     EP+ =       43.985 ( IN Y+ COORD.)
INTERCEPT                   AP  =       -0.145 ( IN U+ COORD.)
KARMAN COEFFICIENT          VK  =        0.316
WAKE STRENGTH               PI  =        0.066
BOUNDARY LAYER THICKNESS    D+  =     1786.635 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY     VM+ =       23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	101.605	4.621	14.363	0.057	-2.867	9.600	-0.543	0.016	0.276
2	128.892	4.859	15.245	0.072	-2.629	8.718	0.080	0.026	0.351
3	156.091	5.050	15.854	0.087	-2.438	8.110	0.093	0.037	0.426
4	183.206	5.211	16.412	0.103	-2.277	7.551	0.341	0.051	0.501
5	210.245	5.348	16.845	0.118	-2.140	7.118	0.330	0.068	0.576
6	264.116	5.576	17.501	0.148	-1.912	6.462	0.013	0.106	0.724
7	290.961	5.673	17.908	0.163	-1.815	6.055	0.497	0.128	0.797
8	344.500	5.842	18.355	0.193	-1.646	5.608	0.078	0.178	0.942
9	397.860	5.986	18.768	0.223	-1.502	5.195	-0.130	0.235	1.085
10	451.149	6.112	19.218	0.253	-1.376	4.745	0.125	0.298	1.225
11	504.357	6.223	19.451	0.282	-1.265	4.512	-0.451	0.368	1.362
12	557.553	6.324	19.750	0.312	-1.165	4.213	-0.540	0.443	1.494
13	637.430	6.457	20.246	0.357	-1.031	3.718	-0.194	0.565	1.685
14	744.350	6.613	20.729	0.417	-0.876	3.234	-0.228	0.741	1.920
15	879.220	6.779	21.308	0.492	-0.709	2.655	0.021	0.975	2.177
16	1015.707	6.923	21.706	0.569	-0.565	2.257	-0.261	1.214	2.383
17	1152.377	7.050	22.320	0.645	-0.439	1.643	0.770	1.440	2.523
18	1289.047	7.162	22.740	0.721	-0.326	1.224	1.083	1.641	2.587
19	1425.717	7.262	23.074	0.798	-0.226	0.889	1.157	1.805	2.563
20	1562.387	7.354	23.499	0.874	-0.134	0.464	1.810	1.923	2.441
21	1699.057	7.438	23.766	0.951	-0.050	0.197	1.818	1.988	2.210
22	1786.635	7.488	23.963	1.000	0.000	0.000	2.000	2.000	2.000

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LAW TYPE 1 : LN(Y+)
USING  18 POINTS ( PER =   72.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE  SE   =   0.517E-01
2ND.-ORDER REGR.COEFF.      B(2)=   0.247E-06
VIRTUAL ORIGIN DISTANCE     EPS =      0.00195 ( IN METERS )
VIRTUAL ORIGIN DISTANCE     EP+ =       53.361 ( IN Y+ COORD.)
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INTERCEPT                     AP  =     -0.949 ( IN U+ COORD.)
KARMAN COEFFICIENT            VK  =      0.305
WAKE STRENGTH                 PI  =      0.047
BOUNDARY LAYER THICKNESS      D+  =   1796.010 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY       VM+ =     23.963 ( IN U+ COORD.)
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LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	110.981	4.709	14.363	0.062	-2.784	9.600	-0.993	0.019	0.400
2	138.268	4.929	15.245	0.077	-2.564	8.718	0.054	0.029	0.497
3	165.466	5.109	15.854	0.092	-2.385	8.110	0.176	0.042	0.593
4	192.582	5.261	16.412	0.107	-2.233	7.551	0.568	0.056	0.689
5	219.620	5.392	16.845	0.122	-2.101	7.118	0.581	0.073	0.783
6	273.492	5.611	17.501	0.152	-1.882	6.462	0.159	0.112	0.967
7	300.337	5.705	17.908	0.167	-1.788	6.055	0.809	0.135	1.058
8	353.876	5.869	18.355	0.197	-1.624	5.608	0.212	0.186	1.234
9	407.256	6.009	18.768	0.227	-1.484	5.195	-0.106	0.243	1.406
10	460.525	6.132	19.218	0.256	-1.361	4.745	0.200	0.307	1.571
11	513.733	6.242	19.451	0.286	-1.252	4.512	-0.622	0.377	1.730
12	566.928	6.340	19.750	0.316	-1.153	4.213	-0.784	0.453	1.881
13	646.806	6.472	20.246	0.360	-1.021	3.718	-0.375	0.575	2.095
14	753.725	6.625	20.729	0.420	-0.868	3.234	-0.497	0.750	2.350
15	888.596	6.790	21.308	0.495	-0.704	2.655	-0.248	0.984	2.615
16	1025.083	6.933	21.706	0.571	-0.561	2.257	-0.713	1.220	2.809
17	1161.753	7.058	22.320	0.647	-0.436	1.643	0.610	1.445	2.918
18	1298.423	7.169	22.740	0.723	-0.324	1.224	0.967	1.645	2.931
19	1435.093	7.269	23.074	0.799	-0.224	0.889	1.004	1.807	2.838
20	1571.763	7.360	23.499	0.875	-0.133	0.464	1.831	1.924	2.627
21	1708.432	7.443	23.766	0.951	-0.050	0.197	1.786	1.988	2.289
22	1796.010	7.493	23.963	1.000	0.000	0.000	2.000	2.000	2.000

```
LAW TYPE 1 : LN(Y+)
USING  19 POINTS ( PER =   80.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE    SE  =   0.970E-01
2ND.-ORDER REGR.COEFF.        B(2)=  -0.428E-06
VIRTUAL ORIGIN DISTANCE       EPS =     0.00218 ( IN METERS )
VIRTUAL ORIGIN DISTANCE       EP+ =      59.480 ( IN Y+ COORD.)
INTERCEPT                     AP  =      -1.451 ( IN U+ COORD.)
KARMAN COEFFICIENT            VK  =       0.298
WAKE STRENGTH                 PI  =       0.036
BOUNDARY LAYER THICKNESS      D+  =    1802.130 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY       VM+ =      23.963 ( IN U+ COORD.)
```

LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	117.100	4.763	14.363	0.065	-2.734	9.600	-1.453	0.021	0.522
2	144.387	4.972	15.245	0.080	-2.524	8.718	0.012	0.032	0.640
3	171.586	5.145	15.854	0.095	-2.352	8.110	0.248	0.044	0.756
4	198.701	5.292	16.412	0.110	-2.205	7.551	0.787	0.059	0.871
5	225.739	5.419	16.845	0.125	-2.077	7.118	0.828	0.076	0.983
6	279.611	5.633	17.501	0.155	-1.863	6.462	0.314	0.116	1.202
7	306.456	5.725	17.908	0.170	-1.772	6.055	1.126	0.139	1.309
8	359.995	5.886	18.355	0.200	-1.611	5.608	0.361	0.191	1.516
9	413.375	6.024	18.768	0.229	-1.472	5.195	-0.062	0.249	1.714

10	466.644	6.146	19.218	0.259	-1.351	4.745	0.295	0.313	1.903
11	519.852	6.254	19.451	0.288	-1.243	4.512	-0.765	0.383	2.083
12	573.048	6.351	19.750	0.318	-1.146	4.213	-0.997	0.459	2.253
13	652.925	6.481	20.246	0.362	-1.015	3.718	-0.528	0.581	2.488
14	759.845	6.633	20.729	0.422	-0.864	3.234	-0.736	0.756	2.763
15	894.715	6.797	21.308	0.496	-0.700	2.655	-0.491	0.989	3.036
16	1031.202	6.938	21.706	0.572	-0.558	2.257	-1.135	1.225	3.219
17	1167.872	7.063	22.320	0.648	-0.434	1.643	0.469	1.449	3.298
18	1304.542	7.174	22.740	0.724	-0.323	1.224	0.864	1.647	3.263
19	1441.212	7.273	23.074	0.800	-0.223	0.889	0.862	1.809	3.102
20	1577.882	7.364	23.499	0.876	-0.133	0.464	1.855	1.925	2.807
21	1714.551	7.447	23.766	0.951	-0.050	0.197	1.757	1.986	2.365
22	1802.130	7.497	23.963	1.000	0.000	0.000	2.000	2.000	2.000

```
LAW TYPE 1 : LN(Y+)
USING  20 POINTS ( PER =   88.00 % OF B.LAYER )
STANDARD ERROR OF ESTIMATE  SE  =    0.108E+00
2ND.-ORDER REGR.COEFF.      B(2)=  -0.469E-06
VIRTUAL ORIGIN DISTANCE     EPS =      0.00249 ( IN METERS )
VIRTUAL ORIGIN DISTANCE     EP+ =       68.127 ( IN Y+ COORD.)
INTERCEPT                   AP  =       -2.134 ( IN U+ COORD.)
KARMAN COEFFICIENT          VK  =        0.289
WAKE STRENGTH               PI  =        0.024
BOUNDARY LAYER THICKNESS    D+  =     1810.776 ( IN Y+ COORD.)
REFERENCE FLOW VELOCITY     VM+ =       23.963 ( IN U+ COORD.)
```

LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	125.747	4.834	14.363	0.069	-2.667	9.600	-2.546	0.024	0.799
2	153.034	5.031	15.245	0.085	-2.471	8.718	-0.116	0.035	0.964
3	180.232	5.194	15.854	0.100	-2.307	8.110	0.395	0.048	1.126
4	207.348	5.334	16.412	0.115	-2.167	7.551	1.278	0.064	1.283
5	234.386	5.457	16.845	0.129	-2.045	7.118	1.394	0.082	1.437
6	288.258	5.664	17.501	0.159	-1.838	6.462	0.685	0.122	1.734
7	315.103	5.753	17.908	0.174	-1.749	6.055	1.871	0.146	1.877
8	368.642	5.910	18.355	0.204	-1.592	5.608	0.733	0.198	2.151
9	422.022	6.045	18.768	0.233	-1.456	5.195	0.077	0.256	2.410
10	475.291	6.164	19.218	0.262	-1.338	4.745	0.551	0.321	2.652
11	528.499	6.270	19.451	0.292	-1.231	4.512	-1.047	0.392	2.879
12	581.694	6.366	19.750	0.321	-1.136	4.213	-1.438	0.467	3.090
13	661.572	6.495	20.246	0.365	-1.007	3.718	-0.832	0.589	3.374
14	768.491	6.644	20.729	0.424	-0.857	3.234	-1.239	0.765	3.692
15	903.362	6.806	21.308	0.499	-0.695	2.655	-1.004	0.996	3.982
16	1039.849	6.947	21.706	0.574	-0.555	2.257	-2.060	1.231	4.140
17	1176.519	7.070	22.320	0.650	-0.431	1.643	0.173	1.453	4.153
18	1313.189	7.180	22.740	0.725	-0.321	1.224	0.650	1.650	4.009
19	1449.859	7.279	23.074	0.801	-0.222	0.889	0.555	1.810	3.699
20	1586.528	7.369	23.499	0.876	-0.132	0.464	1.918	1.925	3.211
21	1723.198	7.452	23.766	0.952	-0.050	0.197	1.654	1.988	2.536
22	1810.776	7.502	23.963	1.000	0.000	0.000	2.000	2.000	2.000

```
LAW TYPE 1 : LN(Y+)
USING  21 POINTS ( PER =   95.00 % OF B.LAYER )
```

STANDARD ERROR OF ESTIMATE SE = 0.112E+00
2ND.-ORDER REGR.COEFF. B(2)= 0.302E-06
VIRTUAL ORIGIN DISTANCE EPS = 0.00268 (IN METERS)
VIRTUAL ORIGIN DISTANCE EP+ = 73.333 (IN Y+ COORD.)
INTERCEPT AP = -2.530 (IN U+ COORD.)
KARMAN COEFFICIENT VK = 0.285
WAKE STRENGTH PI = 0.018
BOUNDARY LAYER THICKNESS D+ = 1815.983 (IN Y+ COORD.)
REFERENCE FLOW VELOCITY VM+ = 23.963 (IN U+ COORD.)

LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:

I	Y+	LN(Y+)	U+	Y+/D+	LN(Y/D)	UM-U+	WAKE	COLES	FINLEY
1	130.953	4.875	14.363	0.072	-2.630	9.600	-3.698	0.026	1.084
2	158.241	5.064	15.245	0.087	-2.440	8.718	-0.273	0.037	1.297
3	185.439	5.223	15.854	0.102	-2.282	8.110	0.532	0.051	1.503
4	212.554	5.359	16.412	0.117	-2.145	7.551	1.775	0.067	1.705
5	239.593	5.479	16.845	0.132	-2.025	7.118	1.975	0.085	1.900
6	293.464	5.682	17.501	0.162	-1.823	6.462	1.079	0.126	2.275
7	320.309	5.769	17.908	0.176	-1.735	6.055	2.648	0.150	2.454
8	373.849	5.924	18.355	0.206	-1.581	5.608	1.136	0.202	2.796
9	427.228	6.057	18.768	0.235	-1.447	5.195	0.247	0.261	3.116
10	480.498	6.175	19.218	0.265	-1.330	4.745	0.842	0.326	3.413
11	533.705	6.280	19.451	0.294	-1.225	4.512	-1.302	0.397	3.687
12	586.901	6.375	19.750	0.323	-1.130	4.213	-1.854	0.473	3.939
13	666.779	6.502	20.246	0.367	-1.002	3.718	-1.111	0.595	4.273
14	773.698	6.651	20.729	0.426	-0.853	3.234	-1.723	0.770	4.634
15	908.568	6.812	21.308	0.500	-0.693	2.655	-1.502	1.001	4.941
16	1045.056	6.952	21.706	0.575	-0.553	2.257	-2.980	1.235	5.075
17	1181.726	7.075	22.320	0.651	-0.430	1.643	-0.111	1.456	5.021
18	1318.395	7.184	22.740	0.726	-0.320	1.224	0.446	1.652	4.767
19	1455.065	7.283	23.074	0.801	-0.222	0.889	0.253	1.811	4.304
20	1591.735	7.373	23.499	0.877	-0.132	0.464	1.988	1.926	3.622
21	1728.405	7.455	23.766	0.952	-0.049	0.197	1.632	1.989	2.710
22	1815.983	7.504	23.963	1.000	0.000	0.000	2.000	2.000	2.000

LAW TYPE 1 , U+.VS.LN(Y+) FOR NULL VIRTUAL ORIGIN
USING 5 POINTS (PER = 10.00 % OF B.LAYER)
STANDARD ERROR OF ESTIMATE SE = 0.324E-01
INTERCEPT AP = 4.871 (IN U+ COORD.)
KARMAN COEFFICIENT VK = 0.428
WAKE STRENGTH PI = 0.354
BOUNDARY LAYER THICKNESS D+ = 1742.650 (IN Y+ COORD.)
REFERENCE FLOW VELOCITY VM+ = 23.963 (IN U+ COORD.)

I	Y+	LN(Y+)	U+	DU+	WAKE	COLES	FINLEY
1	57.620	4.054	14.363	9.600	0.023	0.005	0.045
2	84.907	4.442	15.245	8.718	-0.006	0.012	0.070
3	112.106	4.719	15.854	8.110	-0.055	0.020	0.097
4	139.221	4.936	16.412	7.551	0.008	0.031	0.125
5	166.260	5.114	16.845	7.118	0.030	0.045	0.156
6	220.131	5.394	17.501	6.462	0.030	0.078	0.221
7	246.976	5.509	17.908	6.055	0.197	0.097	0.256
8	300.515	5.705	18.355	5.608	0.184	0.143	0.331
9	353.895	5.869	18.768	5.195	0.221	0.197	0.410

10	407.164	6.009	19.218	4.745	0.369	0.258	0.493
11	460.372	6.132	19.451	4.512	0.304	0.325	0.580
12	513.568	6.241	19.750	4.213	0.356	0.399	0.670
13	593.445	6.386	20.246	3.718	0.547	0.520	0.810
14	700.365	6.552	20.729	3.234	0.664	0.697	1.000
15	835.235	6.728	21.308	2.655	0.866	0.935	1.240
16	971.722	6.879	21.706	2.257	0.920	1.180	1.471
17	1108.392	7.011	22.320	1.643	1.291	1.414	1.678
18	1245.062	7.127	22.740	1.224	1.470	1.624	1.851
19	1381.732	7.231	23.074	0.889	1.580	1.796	1.977
20	1518.402	7.325	23.499	0.464	1.828	1.919	2.045
21	1655.072	7.412	23.766	0.197	1.907	1.988	2.043
22	1742.650	7.463	23.963	0.000	2.000	2.000	2.000

```
==========================================================================
 PLOT OF FUNCTIONS UPON RELATIVE DEPTH
 FOR     18 DATA POINTS


===>>  1A):    KARMAN COEFFICIENT

 2) OPTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=      0.0157121
    2-ORDER REGRESSION:        SD=      0.0092664
    3-ORDER REGRESSION:        SD=      0.0092944
    4-ORDER REGRESSION:        SD=      0.0096412
    5-ORDER REGRESSION:        SD=      0.0095224
    6-ORDER REGRESSION:        SD=      0.0099443

 FOR   18 POINTS, BEST REGRESSION FOUND IS OF ORDER     2
 INTERCEPTION COEFFICIENT :    A =       0.2797414
 REGRESSION COEFFICIENTS  :    B = -0.9128894E-01 -0.2342890E-01

===>>  2A):       INTERCEPT

 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=      0.9732492
    2-ORDER REGRESSION:        SD=      0.4656136
    3-ORDER REGRESSION:        SD=      0.4042798
    4-ORDER REGRESSION:        SD=      0.4194705
    5-ORDER REGRESSION:        SD=      0.4102071
    6-ORDER REGRESSION:        SD=      0.4283859

 FOR   18 POINTS, BEST REGRESSION FOUND IS OF ORDER     3
 INTERCEPTION COEFFICIENT :    A =      -3.1477915
 REGRESSION COEFFICIENTS  :    B = -0.8558009E+01 -0.4257598E+01 -0.7010323E+00


===>>  3A):    VIRTUAL  ORIGIN
```

```
 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=      10.9335618
    2-ORDER REGRESSION:        SD=       4.6410946
    3-ORDER REGRESSION:        SD=       3.1311599
    4-ORDER REGRESSION:        SD=       3.2374554
    5-ORDER REGRESSION:        SD=       3.1226657
    6-ORDER REGRESSION:        SD=       3.2567779

 FOR    18 POINTS, BEST REGRESSION FOUND IS OF ORDER     5
 INTERCEPTION COEFFICIENT :   A =       77.4979777
 REGRESSION COEFFICIENTS  :   B =  0.6964263E+02 -0.4478698E+02 -0.1005153E+03
                                  -0.5030829E+02 -0.8068330E+01


===>>  4A):       WAKE STRENGTH

 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=       0.0327162
    2-ORDER REGRESSION:        SD=       0.0251451
    3-ORDER REGRESSION:        SD=       0.0260124
    4-ORDER REGRESSION:        SD=       0.0269943
    5-ORDER REGRESSION:        SD=       0.0269888
    6-ORDER REGRESSION:        SD=       0.0281805

 FOR    18 POINTS, BEST REGRESSION FOUND IS OF ORDER     2
 INTERCEPTION COEFFICIENT :   A =        0.0038534
 REGRESSION COEFFICIENTS  :   B = -0.1639972E+00 -0.3969554E-01

==================================================================================
 PLOT OF FUNCTIONS WITH Y+ COMPUTED FROM BED
 FOR     22 DATA POINTS


===>>  1B):  VELOC. DISTRIBUTION

 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=       0.2623051
    2-ORDER REGRESSION:        SD=       0.0767507
    3-ORDER REGRESSION:        SD=       0.0492415
    4-ORDER REGRESSION:        SD=       0.0487963
    5-ORDER REGRESSION:        SD=       0.0474496
    6-ORDER REGRESSION:        SD=       0.0454786

 FOR    22 POINTS, BEST REGRESSION FOUND IS OF ORDER     6
 INTERCEPTION COEFFICIENT :   A =     -838.8062177
 REGRESSION COEFFICIENTS  :   B =  0.9431317E+03 -0.4325297E+03  0.1049558E+03
                                  -0.1417955E+02  0.1011328E+01 -0.2974120E-01


===>>  2B):  VEL.-DEFECT DISTRIB.
```

```
 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=       0.9162611
    2-ORDER REGRESSION:        SD=       0.4614591
    3-ORDER REGRESSION:        SD=       0.2714390
    4-ORDER REGRESSION:        SD=       0.1575077
    5-ORDER REGRESSION:        SD=       0.0963253
    6-ORDER REGRESSION:        SD=       0.0693818

 FOR    22 POINTS, BEST REGRESSION FOUND IS OF ORDER    6
 INTERCEPTION COEFFICIENT :   A =       11.3615082
 REGRESSION COEFFICIENTS  :   B = -0.6511654E+02  0.2807910E+03 -0.7264764E+03
                                   0.1023807E+04 -0.7334152E+03  0.2090790E+03


===>>  3B):  LOG. LAW OF THE WALL

 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=       0.0323698
    2-ORDER REGRESSION:        SD=       0.0220793
    3-ORDER REGRESSION:        SD=       0.0274289

 FOR     5 POINTS, BEST REGRESSION FOUND IS OF ORDER    2
 INTERCEPTION COEFFICIENT :   A =       8.5669791
 REGRESSION COEFFICIENTS  :   B =  0.7111287E+00  0.1775183E+00


===>>  4B):    WAKE  FUNCTIONS

 2) OBTENTION OF BEST REGRESSION

    1-ORDER REGRESSION:        SD=       0.3175068
    2-ORDER REGRESSION:        SD=       0.0929042
    3-ORDER REGRESSION:        SD=       0.0596061
    4-ORDER REGRESSION:        SD=       0.0590667
    5-ORDER REGRESSION:        SD=       0.0574370
    6-ORDER REGRESSION:        SD=       0.0550514

 FOR    22 POINTS, BEST REGRESSION FOUND IS OF ORDER    6
 INTERCEPTION COEFFICIENT :   A =  -1021.2213332
 REGRESSION COEFFICIENTS  :   B =  0.1138777E+04 -0.5235517E+03  0.1270428E+03
                                  -0.1716351E+02  0.1224152E+01 -0.3599994E-01

                 ==============================================
                 ===    P R O G R A M      V E L M E A S    ===
                 ===            VERSION 1 (1986)            ===
                 ===         MEASUREMENT AND ANALYSES       ===
                 ===    OF VELOCITIES IN TURBULENT FLOWS    ===
                 ==============================================
```

CHAPTER 5

PROGRAM "VELMEAS" USER MANUAL

5.1. Program Operation

The program VELMEAS Version 1 has been written in conversational fashion, but some commands to direct the operating system must be issued first. They are machine dependent, and in some cases, may consist of a large number of instructions. Hence, procedures prepared for each particular machine are preferable. Those developed for the MODCOMP CLASSIC used at the USDA National Sedimentation Laboratory and for the AMDAHL 470/V8 (or for the IBM 4341) used at The University of Mississippi are listed in Appendix B.

Whenever examples of operation are given in this chapter, the symbol ↓ means that the key "Enter" or "Return" has to be pressed once, and options are given between parenthesis (Parenthesis should not be typed). The use of disk files is different in each machine and should follow the instructions that follow and that refer to table 5.1 succeeding.

(1): This is an auxiliary file that has to be created only once before running any job by the following procedure:

```
JOB  ↓
FMFCRE AUX1 A  ↓
FMFCRE AUX2 B  ↓
FMFCRE AUX3 C  ↓
```

(2): The content of this file is lost in the subsequent job.

(3): This file is rewound once the statistical analysis is finished at each probe positioning.

(4): This file contains the Voltage read on the last probe positioning.

(5): Terminal Input by Console.

(6): Terminal-Screen Output.

(7): This file documents the entire procedure and contains useful tables, parameters and regression coefficients obtained. Commonly, it would be sufficient to print it after each application. However, (2) applies, hence the file should be saved into another file when judged convenient.

(8): This should be a different file for each distribution of velocities.

(9): The procedure creates or optionally uses the file "sea####" with characters "####" replaced by an appropiate designation (for instance, sea8601).

(10): The procedure creates or optionally uses the file "lab &1 A" with the filetype "&1" replaced by an appropiate designation (for instance, sea8601).

Table 5.1 : Disk Files used by the program in two different computers

	<-------- MODCOMP --------->			<---------- AMDAHL or IBM ------------>				
File	**Number**	**Name**	**Instructions**	**Number**	**fname**	**ftype**	**fmode**	**Instructions**
FN1	1	aux1	(1)(2)(3)	1	lab	f1	a	(2)(3)
FN2	2	aux2	(1)(2)(3)(4)	2	lab	f2	a	(2)(3)(4)
KO3	3		(5)	6				(5)
KO5	5		(6)	6				(6)
FN12	12	aux3	(1)(2)(7)	12	lab	f12	a	(2)(7)
FN14	14	sea####	(8)(9)	14	lab	&1	a	(8)(10)

On the MODCOMP computer, the procedure SEAPR1 for running the program (Appendix B.1) is executed by simply typing:

```
JOB  ↓
FMF SEAPR1 P  ↓
ASS UJC P     ↓
VELMEAS sea#### (E)  ↓
```

Option E should be included when the file used is an existing one. It should be omitted when it is a new file to be created by the procedure.

On the AMDAHL computer, using Tektronix plotters, the procedure to run the program (Appendix B.2) is executed by typing:

```
PLOT lab &1  ↓
```

If the Vesatec plotter is to be used (Appendix B.3), type:

```
VER lab &1   ↓
```

It is understood that the procedures listed in Appendix B have already been created. The reader working with computers others than those indicated will find the preceding instructions useful in creating his or her own procedures. It should also be noticed that different versions or updatings of the operating systems managing the aforementioned machines may also require minor changes in the provided procedures.

The use of a different analog-to-digital converter may require changes in the subroutine ANLOGO. When implementing the program in another machine, Chapter 4 will assist in identifying problems. If only the boundary layer analysis is required, subroutine ANLOGO may be replaced by a dummy routine. This was done when implementing the program on the AMDAHL computer.

5.2 The Main Menu

Once the program has been started, the user will see a message on the screen identifying the program. A display "Main Menu" will follow immediatelly:

```
OPTIONS:
             STOP AND EXIT                        :  0
             READ RANDOM SIGNALS (ONLY)           :  1
             SAME AS 1, + MEAN, SD & FREQUENCIES  :  2
             SAME AS 2, + SKEWNESS & KURTOSIS     :  3
             TRANSFORM VOLTAGES TO VELOCITIES     :  4
             SAME AS 4, + BOUNDARY LAYER ANALYSIS :  5
             DUMMY (RESERVED FOR FUTURE DEVELOP.) :  6
             REGRESSION ANALYSIS FACILITY         :  7
             PROTECT PREVIOUS RECORDS IN FILE FN14:  8
             ERASE PREVIOUS RECORDS IN FILE FN14  :  9
ENTER YOUR OPTION---
```

This should be answered by the user with one of the numbers to the right in the Main Menu. For instance the user may type:

7 ↓

which would instruct the program to bring up the regression facility (See 5.6). After an option has been fully executed, the Main Menu appears again on the terminal screen so that another option may be executed. Option 0 would terminate the application. Although the menu is self-descriptive (particularly after reading Chapter 4) and the program keeps giving instructions whenever necessary, some recommendations are to be taken into account as follows.

5.3 Options 1,2 and 3

If the user only wants to collect data, option 1 should be used and after samples are collected and program returns to Main Menu, option 0 must be issued; otherwise new information will be written over the first data, destroying it.

Option 2 does the same as option 1 but additionally produces the Mean, the Standard Deviation and the PDF diagram. If the file FN14 is new, option 9 should be used first to set a needed counter of probing positions to zero.

Option 3 does the same as option 2 but additionally produces the Skewness and Kurtosis. The previous notice about FN14 holds (See 5.7 also).

Whenever any of these options is selected, the user will be asked on the screen to:

ENTER "Y" POSITION---

The user should then type a number and then press the "enter" or equivalent key. In boundary layer measurements, this "Y" position registers the distance of the probe with respect to the wall or bed for the purpose of computing distributions, and it is assumed to be given in mm. (milimeters). In other applications that do not require positioning, a dummy number should be entered anyway, to satisfy program requirements.

Next, the screen will read:

IF YOU WISH OLD HEADING, ENTER 0

....NEW HEADING, ENTER 1 -----:

Since a normal application would require successive positionings of the probe, data collecting and analysis, the user may use always the same heading (an 80-character message, including spaces) by entering 1 the first time and 0 the following times. Optionally, by entering 1 each time, the user may write a different message. (After typing 0 or 1, press "enter")

If the user's answer is 1, the next screen question will be:

ENTER DATA HEADING (UP TO 80 CHARACTERS)-----:

Normally operator name, date, and some identification of the test would be included here. (After typing the heading, press "enter")

Finally the user will be required to:

ENTER THE NO. OF SAMPLES (IN THOUSANDS)-----:

Here the user should take into account that the data acquisition system (This is actually machine-dependent and may vary from system to system) takes one sample each hundredth of a second with a tolerance of 0.005 volts. Thus if the operator types:

30 ↓

the program will take 30,000 samples during a period of 5 minutes. The user will see a message on the screen that reads:

W A I T ...(ENTER "E" TO STOP COLLECTING DATA)

which will stand until the period indicated is finished, or the user types E (return is not needed). The option E to interrupt the reading of samples is very useful when testing the behavior of the system or simply to stop collecting information before the end of the given period for any reason, without interrupting the program, and then resuming work.

Except when the operator wants to issue option E, he should do nothing during the sampling period but wait until all samples are read. Then the operator will see on the screen the following message (The elapsed time will be also be printed on FN12):

INITIAL TIME ##############.#####; FINAL TIME ##############.#####

ELAPSED TIME ##############.##### SECONDS

NO. OF SAMPLES = #######

W A I T ....

with "###..." replaced for the appropiate numbers (This convention is used hereafter). This facility will properly act even when the option E is issued.

At this time the sample collecting has finished, and the operator is free to move the probe to next position (in case he or she had issued options 2 or 3). It is convenient to do so immediately for this will give time for the system to accomodate itself to the new position before a new sampling begins. The operator should never type anything on the terminal until instructed by the screen to do so.

Sometimes the elapsed time is not the expected one (such as the 300 seconds in the example given) but more. This is due to the fact that the computer is operating in time sharing mode, resulting in a little larger period (usually less than half a second). This should not concern the investigator, since the subsequent optional statistical and deterministic analysis is made based on the total number of samples and not on time.

If option 1 was issued, the Main Menu will immediatelly appear on screen.

If options 2 or 3 are in execution the screen-indicated "wait" state will stand, and the user should still do nothing but wait until the subsequent automatic statistical analysis prompts him to act.

When the statistical analysis is completed, the following message will be read on screen (It is also printed on FN12 except for the WAIT message):

```
"Y" PROBE POSITION:  ######.###
HEADING ( UP TO 80 CHARACTERS ENTERED PREVIOUSLY BY THE USER )
STATISTICAL ANALYSIS
NUMBER OF SAMPLES              : #######
SECONDS FOR DELAY              :    #####.##
MINIMUM VOLTAGE FOUND          =  ######.### VOLTS
MAXIMUM VOLTAGE FOUND          =  ######.### VOLTS
DATA IS IN MULTIPLES OF           ######.### VOLTS
W A I T ..........
```

The user will wait until the following information appears on screen (See also section 4.9 for an example):

```
#########.-SAMPLES MEAN:     XM=  ######.###
SAMPLE STANDARD DEVIATION:   SM=  ######.###
```

, and the user will be prompted:

```
>>>>------>    ( TO CONTINUE, ENTER 0  )
```

The user should type 0 and press "return" to continue. Then the PDF will be seen on screen (When running the program in the MODCOMP computer, the user may pause at any moment by pressing the A key while holding the "control" key, and then continue by pressing "return"). The PDF will also be written on FN12 (See section 4.9 for an example). At the end, the user will be asked

again:

>>>>------>   (TO CONTINUE, ENTER 0)

The user should type 0 and press "return" to continue.

If option 3 is in effect, the following title will be seen:

VALUES FOUND THROUGH THE CURVE OF FREQUENCIES

Under this title, the Mean, Standard Deviation, Median, Mode, Skewness, and Kurtosis, and then then the Moments about zero and about the mean, as well as Sheppard's corrections and Beta and Gamma coefficients will all be listed. The same will be printed on FN12.

Option 2 is essential to the subsequent boundary layer analysis (option 5), since the obtained Mean is (after transformation, options 4 or 5) the mean velocity at the given position. The standard deviation and the PDF diagram (sent both to the screen and FN12) will give a hint about the readiness of the system for the measurements (see Chapter 4) and about the turbulence in the flow. Option 3 only adds a Skewness and Kurtosis estimation.

At this stage of execution, both options 2 and 3 will add two lines to FN14. The first line contains the given heading. The second contains the value of Y ("position"), the number of samples, the mean (as obtained in volts), the standard deviation, the skewness and the kurtosis (if the latter two values are not obtained, the value 99999.999 will appear instead). In addition, a number (counter) in the first row of file FN14 will be incremented by 1. This number indicates the number of positions probed, data also essential to the procedure of option 5. The user should insure that data from a previous application still stored in FN14 has been eliminated when so desired, because

the new information will follow at the end of the file, and the counter will be incremented accordingly, resulting in a merging of the old and the new measurements, unless appropiate steps are taken to prevent it. A positive verification of FN14 status may be found by issuing the option 4, sub-option 3, as explained in next section. Options 8 and 9, described in section 5.7 also contribute for the management of FN14.

Finally, again the user will read:

>>>>------>   (TO CONTINUE, ENTER 0)

The user will type 0 and press "return" to obtain the Main Menu again. Usually, having positioned the probe in a new position, option 3 will be selected again until all positions have been covered. Then option 0 will be selected to exit the program. Eventually, option 5 may be used to produce a boundary layer analysis, but this requires an attached plotter.

5.4 Option 4

Voltages read by the probe need in general be transformed to a more significant value through some transformation formula. Although the program may be used the same way or easily expanded to accomodate other variables and formulas, it will here be assumed that a transformation to flow velocity is to be accomplished through the law:

$$u = A * V + B * \text{sqrt}(V) + C$$

where V is the voltage, and A, B, and C are coefficients of transformation. The values of A, B, and C are initially set to accomodate the instrumentation used in flume experiments. In general, these values are to be obtained through analysis and calibration, and can be specified by the user as next

described.

Whenever option 4 (or option 5) is selected, the user will see on the screen the following Sub-Menu:

```
OPTIONS:
              GO BACK TO MAIN MENU               :  0
              USE LAST TRANSFORMATION LAW        :  1
              INTRODUCE TRANSFORMATION LAW       :  2 (AND USE IT)
              NO TRANSFORM (JUST PRINT VOLTAGES):  3
ENTER YOUR OPTION---:
```

(The user will type his option and press "enter")

Sub-option 0 will cause return to the Main Menu with no other consequence whatsoever.

Sub-option 1 will use the last transformation introduced (or the aforementioned initial one), transforming the values in FN14 and printing the resulting table on screen and on FN12. Whenever this option is issued a message will be printed on screen (and on FN12) that reads:

```
A TRANSFORMATION FUNCTION HAS BEEN DEFINED BY:
     VELOCITY = A * VOLTS + B * SQRT(VOLTS) + C
, WITH:  A = ######.##### ,  B =  ######.##### , C = ######.##### .
```

The table will follow under the title:

STATISTICAL PARAMETERS OBTAINED

Sub-option 2 will prompt the user to enter the values of A, B, C with the following messages on screen:

INTRODUCE COEFFICIENTS A,B,C, FOR THE EQUATION:

VELOCITY = A * VOLTS + B * SQRT(VOLTS) + C

FIRST THE COEFFICIENT A:-----:

(The user will type the value of A and press "enter")

THEN THE COEFFICIENT B:-----:

(The user will type the value of B and press "enter")

BY LAST THE COEFFICIENT C:-----:

(The user will type the value of C and press "enter")

It should be remembered that once a new transformation law is introduced, it will remain in effect through the entire application unless changed again. A new application will start with the original initial law. Even so, the operator has a new chance to change the law after each measuring sequence.

Finally, sub-option 3 will print the values in FN14 without transformation whatsoever on screen and on FN12.

This option is intended for general purpose dvelopment of the program. When a boundary layer analysis is to be done, option 5 should be used instead.

5.5 Options 5 and 6

Option 5 will do at first exactly the same as option 4 does. Next the user will be asked to provide information. For example, for the flume experiments conducted at the USDA National Sedimentation Laboratory, this information is contained in the Operator's Form (Appendix C). The screen will read:

ENTER WATER TEMPERATURE (CELSIUS)-----:

The user should enter the water temperature (in degrees Celsius) at the time the experiment was conducted. For instance:

30.5 ↓

Next the screen will read (user's answer is ommitted in next 4 questions):

ENTER DEPTH (INCHES)-----:

The user should enter the depth (in inches) at the probe vertical. Next:

ENTER DISCHARGE MANOMETER READING (IN.HG.)-----:

The user should enter the Venturi's mercury-manometer reading (in inches) or equivalent. Next:

ENTER FREE-SURFACE SLOPE-----:

The user should enter the free surface slope. Finally:

ENTER CHANNEL WIDTH (FEET)----:

The user should enter the channel width at the probe position (in feet). For the conducted experiments this value was always 1.972 feet; for other applications this would, of course, be some other value. The program makes the necessary unit conversions to SI units.

After the channel width is entered, the screen will read:

```
THUS
TGC = ######.###        DEP = ######.###
DH  = ######.###        SLP = ##.#######
BFL = ######.###
IF VALUES ARE CORRECT,  ENTER   0 ,IF VALUES ARE WRONG,  ENTER  1
```

These are the same values entered by the user (in their original units), who may then proceed to correct them (by entering 1) or to accept them (by entering 0). When the values are correct, a similar message will be printed

in FN12.

Before this reading task, a number of computations have already been made (See section 4.7). Their are printed in FN12 (See section 4.10 before the title "SIDE-WALL CORRECTION PARAMETERS:"). Results of following computations will continue to be written on FN12 without indication on screen.

After the user has entered:

0 ↓

the screen will read:

TO PLOT THE VIRTUAL-ORIGIN SEARCH:

ENTER 1 (PEN PLOTTER) OR 2 (TEKTRONIX) OR 3 (VERSATEC)

OTHERWISE, ENTER 0 :

The answer will depend primarily on whether a plotting of the virtual-origin search is required or not, and secondarily on the computer and plotter in use (See 4.2 and Appendix B). If the answer is 0, the origin search will be conducted, beginning with the 4 points nearest to the wall, up to the total number of points measured. This search will not be plotted, since a plot has not been requested, but the results will be printed on FN12 anyway.

Let us assume the program is being run in the AMDAHL computer, the Versatec plotter is being used, and the user wants to plot the search. The operator will enter:

3 ↓

Next, the user will be questioned (valid for any sub-option, including 0):

ENTER CASE NUMBER (UP TO FOUR FIGURES):

The user will enter an up-to-4-characters alfa-numeric identifier, for

instance (It will be written in all subsequent plots following the words "CASE NUMBER"):

A61

The following message will be seen on screen (any sub-option):

SURFACE VALUES HAS BEEN ADDED TO Y+,U+ LAW AS THE POINT NUMBER ##

BOUNDARY LAYER THICKNESS D+ = #####.### (IN Y+ COORD.)

REFERENCE FLOW VELOCITY UM+ = #####.### (IN U+ COORD.)

Next the Versatec procedure will write a message on the screen while creating a file in the user minidisk containing the plot.

If instead of sub-option 3 , the sub-option 2 is under use (that is, the terminal is a graphic Tektronix one), the screen will automatically be cleared and the user should type C ↓ and then again (when prompted on screen) C ↓. The plot will appear on screen. When finished, the operator may submit the plot to the Tektronix hardcopier (when attached) by pressing the "copy" key. When finished, a dot appears on top-center screen, and the user will sequentially type E ↓ (this will clear the screen) and C ↓.

If instead of 3 or 2, sub-option 1 is under use (that is, a pen-plotter is attached to any terminal connected to the computer), the user should first set up the plotter with paper measuring 11"(horizontal)x 8.5"(vertical). If it is a Tektronix pen-plotter the operator should type C ↓ (These and the next commands are not necessary for the Hewlett-Packard plotter). The plot will be executed. Again the user will type C ↓. If a pen plotter is used, a different pen will be used for each search.

Up to seven searchs will be executed in a single plot. At its end, the user

will see the message (if NI, the number of points used in the last virtual-origin search is less than MAX.NI the total number of points):

IF YOU LIKE TO RESTART THE ORIGIN SEARCH, ENTER 2
IF YOU LIKE TO CONTINUE THE ORIGIN SEARCH, ENTER 1
(LAST NI = ##, MAX.NI = ##)
OTHERWISE, ENTER 0

If the user types 0 ↓, the origin search will finish, and the program will continue with the next task (plotting obtained functions upon y/δ). If the user types 1 ↓, seven additional searchs (supposing the last NI is still smaller than MAX.NI) will be executed and the last message will appear again. If the user chooses to continue issuing sub-option 1, the program will at some point search for NI = MAX.NI, and the the screen will read:

IF YOU LIKE TO RESTART THE ORIGIN SEARCH, ENTER 2
OTHERWISE, ENTER 0

If the user types 2 ↓, the search will again begin with 4 points. After the user finally issues the sub-option 0, the screen will read:

TO PLOT FUNCTIONS UPON RELATIVE DEPTH,
ENTER 1 (PEN PLOTTER) OR 2 (TEKTRONIX) OR 3 (VERSATEC)
OTHERWISE, ENTER 0 :

Even if no plot was made of the origin search, this new plotting may be executed. It will use all the searchs made in the previous step. Hence the user may specify this plot to cover 7 or 14, etc. up to the total number of points.

This plot uses an area of 15"(horizontal)x 11"(vertical) since it actually draws 4 graphs. If a pen-plotter is used the paper should have these dimensions. If a graphic Tektronix terminal is used, after the first C ↓ issued, a window command should be used by sequentially typing: W ↓ 0,0 ↓ 15 11 ↓ C ↓ and then continuing as in previous smaller plottings.

In all other respects, the procedure is similar to previous ones. When the plot is finished, the same message will appear on the screen. This is useful for repeating the same graph, and even more so when using a graphic terminal and pen-plotter simultaneously and a preview is wanted.

When the user finally issues the sub-option 0, the screen will read:

LAWS OF THE WALL AND THE WAKE AND VELOCITY-DEFECT LAW:

ENTER 1 (PEN PLOTTER) OR 2 (TEKTRONIX) OR 3 (VERSATEC)

OTHERWISE, ENTER 0 :

All the instructions given for the previous plotting are valid for the present one. Issuing sub-option 0 will make the Main Menu appears again on the screen (See section 5.2). If then the option 0 is issued, the application will immediatly finish, except when the Versatec plotter is in use. In the later case, a message will still be read on the screen, beginning with: "DO YOU WANT PLOT OR STOP ?", et cetera. To actually submit the plotting to the off-line Versatec copier, the user will type PLOT ↓ , and wait until the process finish.

Option 6 is a dummy option. It has been reserved for future developments.

5.6 <u>Option 7</u>

This option calls the Regression analysis facility, which is independent of the rest of the analysis incorporated to the program. It has been included as a useful additional tool. When this option is selected, the screen will read:

```
OPTIONS:
                GO BACK TO MAIN MENU                      :  0
                VISC=FUNC(TEMP.CELSIUS)                   :  1
                F=FUNC(LN(R/F)) LAW FOR SMOOTH WALLS      :  2
                Y=FUNC(X)       LAW TO TYPE ON TERMINAL   :  3
                Y=FUNC(LN(X))   LAW TO TYPE ON TERMINAL   :  4
            LN(Y)=FUNC(X)       LAW TO TYPE ON TERMINAL   :  5
            LN(Y)=FUNC(LN(X))   LAW TO TYPE ON TERMINAL   :  6
ENTER YOUR OPTION----
```

Sub-options 1 and 2 may be used only if none of the main options 3 to 5 have been used. These two options obtain regressions of two functions used in the analysis of the boundary layer, i.e. the viscosity as a function of temperature, and the f=function(R/f) law for smooth walls (See section 2.7). Other sub-options are self-explained in the given Sub-Menu. Whenever the user types, for instance,

3 ↓

the screen will read:

```
1) REGRESSION ANALYSIS WITH SCALES:
    1 FOR X
    1 FOR Y
 ( 1=NATURAL SCALE, 2 LOGARITHMIC SCALE )
FOR UP TO  ## DATA PAIRS X,Y
ENTER NUMBER OF PAIRS----
```

The user will enter the number of pairs, for instance:

35 ↓

and then, successively the two values of X and Y after each prompt to (Values will also be promted on FN12):

ENTER A DATA PAIR X,Y

When the program finds that the given number of pairs has been entered, it writes on screen:

IF YOU LIKE TO CHANGE SOME DATA, ENTER 1

IF NOT, ENTER 0 ------:

If the answer is 1 ↓, the screen will read:

ENTER "I", "X(I)", "Y(I)" VALUES-------:

The user will enter the required values ("I" should correspond to the value to be corrected). A message documenting the change will be sent to FN12.

Whenever the user answers 0 ↓ , a best-polynomial regression will be obtained, defined as the one of the first up to the sixth order that registers the least standard error of estimate (after transformation of coordinates in agreement to the sub-option selected).

Regression coefficients and standard error of estimate will be documented in FN12. The user will have the opportunity to obtain interpolated values (through the regression) since the screen will next read:

IF YOU LIKE TO GET A REGRESSION VALUE, ENTER 1

IF NOT, ENTER 0 ------:

If the user types 1 ↓ it will be asked to:

ENTER "X" VALUE-------:

When this is done, both the screen and FN12 will read:

FOR X = #########.##### , Y = #########.#####.

The same message will appear over and over until the user types 0 ↓ , in which case the Sub-Menu will again be written on the terminal screen.

5.7 <u>Options 8 and 9</u>

Collecting data is a tiresome task for any operator, and a mishandling may result in accidental erasing of the table generated in FN14. This file contains all Means, Standard Deviations, Skewnesses and Kurtoses found for each probe positioning. This usually demands several hours of work, including the use of equipment of considerable operative cost. The selection of option 8 will protect FN14 from being erased. The operator should type:

8 ↓

while in the Main Menu, once he or she is sure that collected information will be useful. This will disable option 9, which will remain ineffective even if requested, until the end of the application. Option 9 is intended to clear files at the beginning of measurements, when it is certain that all data in files FN14 and FN12 can be erased, and the counter of positions has to be set to zero. If the application consists only in analysis of previously collected data, option 9 should **not** be used.

While testing the system for readiness for collecting data, the operator will usually obtain data of no practical interest. Before starting the actual data acquisition process, the user should clear files FN14 and FN12. This is done by issuing option 9 by typing:

9 ↓

The user should be certain, before using this command, that those files do not contain useful information. Option 4, sub-option 3 may be used to this effect (See section 5.4).

This option should also be used before any other when FN14 is a new file containing no information. This will create a positioning counter, which will be set to zero.

It is a highly recommended practice to create a "backup" of every file FN14 immediately after an application.

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APPENDIX A

Program VELMEAS Source Code

```
C=====================================================================C
C                 USDA NATIONAL SEDIMENTATION LABORATORY              C
C                   AND  THE UNIVERSITY OF MISSISSIPPI                C
C               ************************************                  C
C               ***  PROGRAM VELMEAS VERSION 1 (1986) ***              C
C               ************************************                  C
C                     DEVELOPED BY SERGIO E. ADEFF                    C
C---------------------------------------------------------------------C
C         FOR THE DETENTION AND ANALYSIS OF VELOCITY PROFILES         C
C         FROM THE MEASUREMENT OF VELOCITIES AT SINGLE POINTS         C
C                      LAST UPDATING: APR-15-87                       C
C---------------------------------------------------------------------C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 XX,YY,XR,YR,HF
C:::::   NEXT    1   LINES      NEEDED        FOR VS FORTRAN VERSION
      CHARACTER*4 A
      COMMON KI5,KO3,IAP
      DIMENSION VFR(50),FRC(50),A(20),Y(50),V(50),QS( 50),S( 50),ERR(50)
     &,IFR(50),GR(50),B( 50),C(50),H(50,50),SK(50),QK(50),W(50),OR(50)
     &,VIB(4),RBB(6),IST(20),YST(20),UST(20),XX(52),YY(52),XR(52),YR(52)
     &,HF(50,20),GA(10),WG(10)
      DATA DVCL,SS,NC,CA,CB,CC,NDI,NDJ,DIA,DA,DB/5.D-3,99999.999,0,0.D0
     &,.758D0,0.D0,50,20,3.1D0,.17946D0,0.D0/,SI1,SI2,GRA/.3048D0
     &,.0254D0,9.8162D0/,A/20*'    '/,MD,MF/52,20/,NPV,NPF/4,6/,NL/10/
     &,B/1.93D-5,1.67D-5,1.41D-5,1.21D-5,1.05D-5,.93D-5,.823D-5,.736D-5
     &,.61D-5,.476D-5,.385D-5,.319D-5,38*0.D0/,IFR/32,40,50,60,70,80,90
     &,100,120,150,180,212,38*0/,NVS/12/,C/.3D6,.4D6,.6D6,.8D6,1.D6
     &,1.5D6,2.D6,3.D6,4.D6,6.D6,8.D6,10.D6,11.D6,12.D6,13.D6,14.D6
     &,16.D6,33*0.D0/,S/.0317D0,.0268D0,.0273D0,.0257D0,.0245D0,.0227D0
     &,.0214D0,.0199D0,.0189D0,.0177D0,.0169D0,.0163D0,.0152D0,.0145D0
     &,.0136D0,.0130D0,.01225D0,33*0.D0/,NDW/17/,KUSD,KPRC/0,0/
     &,VIA,VIB/-13.23073D0,-.3430623D-1,.3009006D-3,-.1970707070D-5
     &,.5591092D-8/,REA/650.7750135D0/,RBB/-2.6407678D2,4.4532630D1
     &,-3.99393D0,2.008921D-1,-5.372674D-3,5.967903D-5/
C:::::  KI5,KO3/5,3/ FOR MDDCOMP VERSION, /6,6/ FOR VS FORTRAN VERSION
      KI5=6
      KO3=6
C-- MAIN MENU
      IAP=0
      WRITE(KO3,101)
      WRITE(12,101)
    1 WRITE(KO3,104)
    2 WRITE(12,104)
      WRITE(KO3,100)
      READ(KI5,*)ICP
      IF(ICP.LE.0)GO TO 90
      GO TO(5,5,5,50,50,2,41,42,80,2),ICP
C-- MAIN 1,2,3 OPTIONS
    5 WRITE(KO3,110)
      READ(KI5,*)YPC
      CL1=1.E10
      CL2=-1.E10
      SKEW=SS
      QKUR=SS
      FME=SS
```

```
      FMD=SS
C-- GET ANALOG SIGNALS
      CALL ANLOGO(A,CSAMP,NNO,IP40,INUM,MINU,NSEC,CL1,CL2)
      IF(CSAMP.LE.0.)GO TO 1
      REWIND 2
      IF(ICP.EQ.1)GO TO 20
C-- MAIN 2,3 OPTIONS
      SEC=FLOAT(60*MINU)+FLOAT(NSEC)*.01
      WRITE(KO3,111)YPC
      WRITE(KO3,102)A,CSAMP,SEC,CL1,CL2,DVOL
      WRITE(12,111)YPC
      WRITE(12,102)A,CSAMP,SEC,CL1,CL2,DVOL
      WRITE(KO3,103)
C-- GET MEAN, STANDARD DEVIATION AND FREQUENCIES
      CALL STATI1(NDI,A,QSAMP,NNO,IP4C,INUM,DVOL,MCL,VFR,FRQ
     &,CL1,CL2,XMED,SDEV,IFR)
      KUSD=1
C-- MAIN 1,2,3 OPTIONS
   20 WRITE(KO3,106)
      READ(KI5,*)K
      ENDFILE 2
      ENDFILE 1
      IF(ICP.LE.1)GO TO 40
C-- MAIN 2,3 OPTIONS
C-- IF MAIN 3 OPTION, GET SKEWNESS AND KURTOSIS
      IF(ICP.GE.3)CALL STATI2(NDI,MCL,VFR,FRQ,SKEW,QKUR,XMED,DVOL
     &,FME,FMC)
      REWIND 14
      READ(14,*)NPC
      NPN=NPO+1
      REWIND 14
      WRITE(14,107)NPN
      IF(NPO.EQ.0)GO TO 35
      DO 30 I=1,NPC
   30 READ(14,108)
   35 WRITE(14,109)A,YPC,CSAMP,XMED,SDEV,SKEW,QKUR,FME,FMC
      ENDFILE 14
   40 REWIND 1
      REWIND 2
   45 WRITE(KO3,106)
      READ(KI5,*)K
      GO TO 1
C-- MAIN 4,5 OPTIONS
   50 REWIND 14
      KUSD=1
      READ(14,*)NPN
      IF(NPN.EQ.0)GO TO 55
      DO 52 I=1,NPN
   52 READ(14,112)Y(I),CS(I),V(I),S(I),SK(I),CK(I)
   53 WRITE(KO3,116)
C-- SUB-MENU FOR THE MAIN 4,5 OPTION
      READ(KI5,105)IO4
      IF(IO4.LE.0.OR.IO4.GE.4)GO TO 1
      GO TO(66,65,72),IO4
C-- SUB 2 OPTION
```

```
  65  WRITE(KO3,118)
      READ(KI5,*)CA
      WRITE(KO3,120)
      READ(KI5,*)CB
      WRITE(KO3,121)
      READ(KI5,*)CC
C-- SUB 1,2 OPTIONS
  66  DO 68 I=1,NPN
      V(I)=CA*V(I)+CB*DSQRT(V(I))+CC
  68  S(I)=CA*S(I)+CB*DSQRT(S(I))+CC
  69  WRITE(12,122)CA,CB,CC
      WRITE(KO3,122)CA,CB,CC
C-- SUB 1,2,3 OPTIONS
  72  WRITE(12,114)NPN
      DO 75 I=1,NPN
  75  WRITE(12,113)Y(I),CS(I),V(I),S(I),SK(I),CK(I)
C-- IF MAIN 5 OPTION GET VERTICAL PROFILES
      IF(ICP.NE.5)GO TO 1
      CALL DISTRI(NCI,V,S,NPN,AI,B,C,VFR,FRC,GR,H,IR,A,Y,CS,VM,YM,ZM
     &,LMA,SDI,DIA,BFL,GRA,DA,DB,SI1,SI2,VMA,VIA,VIB,NPV,REA,REE,NPF
     &,ERR,IST,YST,UST,NEW,NST,NOJ,OR,IFR,HF,XX,YY,XR,YR,MC,MF,GA,WG,NU)
      GO TO 1
C-- IF MAIN 7 OPTION GET REGRESSIONS FACILITY
  41  CALL REGFAC(KLSC,SI1,NVS,GR,IFR,W,B,QS,NOI,VFR,FRC,SK,CK,H,Y,V
     &,C,S,NCW)
      GO TO 1
C-- AUXILIAR INSTRUCTIONS
  55  WRITE(KO3,115)
      DO 56 I=1,1000
  56  CONTINUE
      GO TO 1
  80  IF(KPRC.EQ.1)GO TO 43
      REWIND 14
      WRITE(14,107)NC
      REWIND 12
      WRITE(12,101)
      GO TO 1
  42  KPRO=1
  43  WRITE(KO3,123)
      GO TO 2
  90  ENDFILE 12
      IF(IAP.EQ.1)CALL PLO(3,2,999)
      STOP
C-- FORMATS:
 100  FORMAT(' OPTIONS:'/
     &'         STOP AND EXIT                          :  0'/
     &'         READ RANDOM SIGNALS ( ONLY )           :  1'/
     &'         SAME AS 1, + MEAN, SD & FREQUENCIES    :  2'/
     &'         SAME AS 2, + SKEWNESS & KURTOSIS       :  3'/
     &'         TRANSFORM VOLTAGES TO VELOCITIES       :  4'/
     &'         SAME AS 4, + BOUNDARY LAYER ANALYSIS   :  5'/
     &'         DUMMY (RESERVED FOR FUTURE DEVELOP.)   :  6'/
     &'         REGRESSION ANALYSIS FACILITY           :  7'/
     &'         PROTECT PREVIOUS RECORDS IN FILE FN14:  8'/
     &'         ERASE PREVIOUS RECORDS IN FILE FN14    :  9'/
```

```
     &' ENTER YOUR OPTION---I1')
 101  FORMAT(/ 18X,'=================================================='
     &       / 18X,'===  USDA NATIONAL SEDIMENTATION LABORATORY  ==='
     &       / 18X,'===                    AND                   ==='
     &       / 18X,'===       THE UNIVERSITY OF  MISSISSIPPI     ==='
     &       / 18X,'=================================================='/)
 102  FORMAT(' ',20A4/' STATISTICAL ANALYSIS'//
     &' NUMBER OF SAMPLES          :',2X,F7.0/
     &' SECONDS FOR DELAY          :',F8.2/
     &' MINIMUM VOLTAGE FOUND      =',F9.3,' VOLTS'/
     &' MAXIMUM VOLTAGE FOUND      =',F9.3,' VOLTS'/
     &' DATA IS IN MULTIPLES OF    ',F9.3,' VOLTS')
 103  FORMAT(/' W A I T .......')
 104  FORMAT(/ 18X,'=================================================='
     &       / 18X,'===     P R O G R A M      V E L M E A S    ==='
     &       / 18X,'===              VERSION 1 (1986)            ==='
     &       / 18X,'===          MEASUREMENT AND ANALYSES        ==='
     &       / 18X,'===     OF VELOCITIES IN TURBULENT FLOWS     ==='
     &       / 18X,'=================================================='/)
 105  FORMAT(I1)
 106  FORMAT(/' >>>>------>     ( TO CONTINUE, ENTER 0  )')
 107  FORMAT(I5)
 108  FORMAT( /)
 109  FORMAT(' ',20A4/F10.3,F9.0,6F10.3)
 110  FORMAT(' ENTER "Y" POSITION---')
 111  FORMAT(/' "Y" PROBE POSITION:',F11.3/)
 112  FORMAT(/F10.3,F9.0,6F10.3)
 113  FORMAT(F10.3,F9.0,6F10.3)
 114  FORMAT(//' STATISTICAL PARAMETERS OBTAINED:'
     &/7X,'POS',2X,'SAMPLES',6X,'MEAN',6X,'S.D.',6X,'SKEW',6X,'KURT'/)
 115  FORMAT(/' NO RECORDS ARE AVAILABLE !!!!!!!! '/)
 116  FORMAT(' OPTIONS:'/
     &'          GO BACK TO MAIN MENU                 :  0'/
     &'          USE LAST TRANSFORMATION LAW          :  1  '/
     &'          INTRODUCE TRANSFORMATION LAW         :  2  ( AND USE IT)'/
     &'          NO TRANSFORM ( JUST USE VOLTAGES ) :  3'/
     &' ENTER YOUR OPTION---I1')
 118  FORMAT(//' INTRODUCE COEFFICIENTS  A,B,C, FOR THE EQUATION:'
     &/'     VELOCITY =  A * VOLTS +  B * SQRT(VOLTS)  +  C'/
     &/' FIRST THE COEFFICIENT A:-----:')
 120  FORMAT(' THEN THE COEFFICIENT B:-----:')
 121  FORMAT(' BY LAST, THE COEFFICIENT C:-----:  ')
 122  FORMAT(/' A TRANSFORMATION FUNCTION HAS BEEN DEFINED BY:'
     &/'        VELOCITY = A * VOLTS +  B * SQRT(VOLTS)  +  C'
     &/' , WITH:  A =',F12.5,' ,  B =',F12.5,' , C =',F12.5,' .'/)
 123  FORMAT(/' ***            OUTPUT FILES HAS BEEN PROTECTED         ***'
     &/' YOU CANNOT ERASE THEM UNLESS YOU RE-START THE PROCEDURE'/)
      END
C===================================================================
      SUBROUTINE DISTRI(NDI,U,S,N,A,B,C,E,F,G,H,I,TIT,Y,Z,VM,YM,ZP,L
     &,SD,DIA,BFL,GRA,CA,CB,SI1,SI2,VMA,VIA,VIB,NPV,REA,RBB,NPF,ERR,IST
     &,YST,UST,NEW,NST,NOJ,O,IFR,HF,XX,YY,XR,YR,MD,MF,GA,WG,NU)
C                ANALYSIS OF DISTRIBUTION OF VELOCITIES
      IMPLICIT REAL*8 (A-H,O-Z)
C:::::    NEXT    1   LINES        NEEDED        FOR VS FORTRAN VERSION
```

```
      CHARACTER*4 LTT,TIT
      REAL*4 XX,YY,XR,YR,HF
      COMMON KI5,KC3,IAP
      DIMENSION U(NDI),S(NDI),E(NDI),F(NDI),Y(NDI),Z(NDI),ERR(NDI)
     &,O(NDI),B(NDI),C(NDI),G(NDI),TIT(20),H(NDI,NDI),VIB(NPV),RBB(NPF)
     &,IFR(NDI),IST(NDJ),YST(NDJ),UST(NDJ),HF(NDI,MF),XX(MD),YY(MC)
     &,XR(MD),YR(MC),JOK(4),GA(NU),WG(NU)
      DATA TOL/1.D-10/,A1,A2,C3,A4/3.6D-4,-5.94D-3,5.67D-3,1.78605D-1/
      WRITE(12,18)
   18 FORMAT(//' VELOCITY DISTRIBUTION TREATMENT'/
     &/' 0) POINTS ARE REARRENGED (IF NECESSARY ) FROM BED TO WATER '
     &,'SURFACE'//' 1) POSITION CORRECTION FOR BOTTOM PROXIMITY'/)
      CALL GAUSS1(GA,WG,NU,NU)
      IT=0
      DO 60 I=2,N
      L=1
   48 IF(Y(I).GE.Y(I-1))GO TO 60
      DO 50 J=L,I
      IF(Y(I).GE.Y(J))GO TO 50
      L=J
      C1=Y(J)
      C2=U(J)
      Y(J)=Y(I)
      U(J)=U(I)
      Y(I)=C1
      U(I)=C2
      IT=1
      GO TO 48
   50 CONTINUE
   60 CONTINUE
      IF(IT.EQ.0)GO TO 70
      WRITE(12,65)(I,Y(I),U(I),I=1,N)
   65 FORMAT(/' POINTS HAVE ACTUALLY BEEN REARRENGED FROM BOTTOM TO '
     &,'SURFACE:'/2(4X,'I',11X,'Y',11X,'U !')/(2(I5,2F12.3,' !')))
   70 CC=-1.D7
      C1=A1/DIA**2
      C2=A2/DIA
      C4=A4*DIA
      YMC=10.5*DIA
      VM=CO
      YMA=CO
      SD=-CO
C-- GET LOG(Y) ,MAXIMUM LEVEL AND MAXIMUM VELOCITY
      DO 4 J=1,N
      IF(Y(J).GT.YMC)GO TO 3
      COR=C4+(C3+(C2+C1*Y(J))*Y(J))*Y(J)
      Y(J)=Y(J)+COR
      WRITE(12,8)J,COR,Y(J)
    8 FORMAT(' LEVEL #',I4,' : COR=',F10.5,' , NEW Y=',F10.3)
    3 IF(U(J).LT.VM)GO TO 2
      VM=U(J)
      M=J
    2 IF(Y(J).LT.YMA)GO TO 4
      YMA=Y(J)
      L=J
```

```
    4  CONTINUE
       ZMA=DLOG(YMA)
C-- GET REGRESSIONS AND SELECT THE BEST ONE ( SMALLEST SD )
       CALL BSTREG(6,NDI,Y,U,N,A,B,C,E,S,G,H,I,Z,F,SD,2,1)
C-- SEARCH FOR THE MAXIMUM VELOCITY IN THE REGRESSION
       WRITE(12,36)
   36  FORMAT(//' 3) COMPUTE MAXIMUM VELOCITY IN THE REGRESSION'/)
       IF(I.EQ.1)GO TO 28
       ZP=Z(M)
       VC=VM
       DZ=ZP/N*.1
   21  DO 22 J=1,500
       VA=VC
       ZP=ZP-DZ
       VC=FREG1(ZP,A,C,NDI,I)
       IF(VC.LT.VA)GO TO 26
       IF(ZP.GT.ZMA)GO TO 28
   22  CONTINUE
   26  IF(DABS(DZ).LT.TOL)GO TO 30
       DZ=-DZ*.4
       GO TO 21
C-- MAXIMUM VELOCITY FOUND AT THE MAXIMUM LEVEL
   28  ZP=ZMA
       VC=FREG1(ZP,A,C,NDI,I)
C-- MAX. VELOC. FOUND AT INTERMEDIATE LEVEL
   30  YM=DEXP(ZP)
       WRITE(12,42)VC,YM,ZP,YMA
   42  FORMAT(/' MAXIMUM VELOCITY FOUND FOR SELECTED REGRESSION:'/10X
      &,'UM=',F12.5,9X,'AT YM=',F12.5/24X,'  ( LN(YM) = ZM=',F12.5
      &,' )'/10X,'MAXIMUM LEVEL ACCOUNTED  YMA =',F12.5/)
       DO 40 K=1,N
       B(K)=FREG1(Z(K),A,C,NDI,I)/VC
       G(K)=Y(K)/YMA
       Z(K)=Z(K)/ZMA
       F(K)=U(K)/VC
   40  ERR(K)=(F(K)-B(K))/B(K)*100.
       WRITE(12,46)(K,Y(K),U(K),G(K),Z(K),F(K),B(K),ERR(K),K=1,N)
   46  FORMAT(//' 4)  VALUES OBTAINED:'//'     K',9X,'Y',9X,'U',6X,'Y/YM'
      &,6X,'Z/ZM',6X,'U/UM',5X,'UR/UM',6X,'ERR%'/(I5,7F10.3))
C-- DO SIDE-WALL CORRECTION
       CALL WALL(BFL,GRA,DA,DB,SI1,SI2,Y,U,G,Z,B,F,E,NCI.N,VMA,VIA,VIB
      &,NPV,REA,RBB,NPF,DEP,FRB,RBD,SHB,VIS,SLP,DEP,YP,UP)
       VP=FREG1(DLOG(DEP*1000.),A,C,NDI,I)*UP
       DP=DEP*YP
       VMA=VC*UP
       YMA=YM*YP*.001
       IF(VP.LT.VMA)GO TO 77
       VMA=VP
       YMA=DP
C-- GET NEW BEST REGRESSION IN LN(Y+) , U+ COORDINATES
   77  DO 73 K=1,N
       IFR(K)=0
   73  Z(K)=DLOG(G(K))
       CALL BSTREG(6,NDI,Z,B,N,A,F,C,E,S,ERR,H,I,Y,U,SD,1,1)
       DO 54 K=1,N
```

```
      F(K)=FREG1(Z(K),A,C,NCI,I)
   54 ERR(K)=(F(K)-B(K))/B(K)*100.
      WRITE(12,56)(K,G(K),Z(K),F(K),B(K),ERR(K),K=1,N)
   56 FORMAT(//' NEW VALUES OBTAINED:'//'     K',9X,'Y+',5X,'LN(Y+)'
     &,9X,'U+',8X,'UR+',7X,'ERR%'/(I5,5F11.3))
C-- ELIMINATE (BUT STORE) UP TO 10 POINTS WITH ERR = OR > 0.5
      NEW=N
      NST=0
      ELI=0.5
      DO 80 L=1,N
      EM=ELI
      K=0
      DO 71 M=1,N
      IF(DABS(ERR(M)).LE.EM)GO TO 71
      EM=DABS(ERR(M))
      K=M
   71 CONTINUE
      IF(K.EQ.0.OR.EM.LE.ELI.OR.NST.GT.10)GO TO 81
      NST=NST+1
      IST(NST)=K+NST-1
      NEW=N-NST
      YST(NST)=G(K)
      UST(NST)=B(K)
      DO 78 J=K,NEW
      G(J)=G(J+1)
      Z(J)=DLOG(G(J))
   78 B(J)=B(J+1)
      CALL BSTREG(6,NCI,Z,B,NEW,A,F,C,E,S,ERR,H,I,Y,U,SD,1,1)
C-- NOTE REGRESSION VALUES ARE DIMENSIONLESS
      DO 74 K=1,NEW
      F(K)=FREG1(Z(K),A,C,NCI,I)
   74 ERR(K)=(F(K)-B(K))/B(K)*100.
      WRITE(12,76)YST(NST),(ERR(K),K=1,NEW)
   76 FORMAT(//' POINT Y =',F11.3,' , ELIMINATED. NEW ERROR VALUES:'
     &/(8F10.3))
   80 IF(NST.EQ.NDJ)GO TO 81
   81 WRITE(K03,82)NST,N
      WRITE(12,82)NST,N
   82 FORMAT(/I5,' POINTS ELIMINATED FROM ',I5,' ORIGINAL POINTS. <<=='')
C-- COMPUTE MEAN VELOCITY UA AND ROUGH-CHANNEL FLOW RESISTANCE
      YMI=G(1)
      ZMI=Z(1)
      CALL MFLOW(SHB,VIS,SLP,GRA,FCW,UA,UAP,DEP,A,C,NDI,NEW,I,GA,WG,NL
     &,YMI,ZMI)
C-- FIND VIRTUAL ORIGIN DISTANCE EPSILON ON "NEW" NUMBER OF POINTS
      CALL ORIGIN(Y,U,G,Z,B,F,E,NDI,NEW,DP,VP,H,S,C,YP,UP,YMA,VMA,A,C,I
     &,SHB*1.03,VIS*1.06,IFR,HF,MF,IOK,XX,YY,XR,YR,MD,LTT,JOK,VK,AB,PI)
C-- PLOT FUNCTIONS OBTAINED DURING ORIGIN SEARCH
      CALL KARMAN(Y,U,G,Z,B,F,E,NDI,NEW,DP,VP,H,S,C,YP,UP,YMA,VMA,A,C
     &,I,0.,0.,IFR,HF,MF,IOK,XX,YY,XR,YR,MD,LTT)
C-- PLOT FUNCTIONS OBTAINED WITH NULL VIRTUAL ORIGIN
      CALL DEFECT(Y,U,G,Z,B,F,E,NDI,NEW,DP,VP,H,S,C,YP,UP,YMA,VMA,A,C
     &,I,VK,AB,PI,IFR,HF,MF,IOK,XX,YY,XR,YR,MD,LTT,JOK)
      RETURN
      END
```

```
C==============================================================================
      SUBROUTINE WALL(BFL,GRA,DA,DB,SI1,SI2,Y,U,G,Z,F,B,E,M,N,VPA,VIA
     &,VIB,NPV,REA,RBB,NPF,DEP,FRB,RBD,SHB,VIS,SLP,CP,YP,UP)
C-- APPLY JOHNSON'S METHOD FOR SIDE-WALL CORRECTION AND GET Y+,U+ VALUES
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON KI5,KO3,IAF
      DIMENSION Y(M),U(M),G(M),Z(M),F(M),B(M),E(M),VIB(NPV),RBB(NPF)
   10 WRITE(KO3,1)
    1 FORMAT(/' ENTER WATER TEMPERATURE (CELSIUS)-----:')
      READ(KI5,*)TGC
      WRITE(KO3,2)
    2 FORMAT(' ENTER DEPTH (INCHES)-----:')
      READ(KI5,*)DEP
      WRITE(KO3,3)
    3 FORMAT(' ENTER DISCHARGE MANOMETER READING (IN.HG)-----:')
      READ(KI5,*)DH
      WRITE(KO3,4)
    4 FORMAT(' ENTER FREE SURFACE SLOPE-----:')
      READ(KI5,*)SLP
      WRITE(KO3,5)
    5 FORMAT(' ENTER CHANNEL WIDTH (FEET)-----:')
      READ(KI5,*)BFL
      WRITE(KO3,7)TGC,DEP,DH,SLP,BFL
    7 FORMAT(/' THUS:'/2X,'TGC=',F12.3,10X,'DEP=',F12.3/2X
     &,'DH =',F12.3,10X,'SLP=',F12.7/2X,'BFL=',F12.3/
     &/'  IF VALUES ARE CORRECT,   ENTER  0 ,'
     &,' IF VALUES ARE WRONG,   ENTER  1 ')
      READ(KI5,9)I
    9 FORMAT(I1)
      IF(I.NE.0)GO TO 10
      WRITE(12,8)TGC,DEP,DH,SLP,BFL
    8 FORMAT(//80('=')/2X,'TGC=',F12.3,' CELSIUS D.,     DEP=',F12.3
     &,' INCHES' /2X,'DH =',F12.3,' IN.HG.     ,     SLP=',F12.7
     &        /2X,'BFL=',F12.3,' FEET'/)
      VIS=DEXP(FREG1(TGC,VIA,VIB,NPV,NPV))
      CFT=(DA*DSQRT(DH)+DB)*SI1**3
      DEP=DEP*SI2
      BFL=BFL*SI1
      DH=DH*SI2
      GS=DSQRT(GRA*SLP)
      ARE=DEP*BFL
      VEL=CFT/ARE
      PER=BFL+2.*DEP
      RAD=ARE/PER
      SHE=GS*DSQRT(RAD)
      FRC=8.*(SHE/VEL)**2
      REY=4.*VEL*RAD/VIS
      RAT=REY/FRC
      FRW=FREG1(DLOG(RAT),REA,RBB,NPF,NPF)
      FRB=FRC+2.*(DEP/BFL)*(FRC-FRW)
      RBD=RAD*FRB/FRC
      SHB=GS*DSQRT(DABS(RBD))
      BST=FRB/FRC
      WST=FRW/FRC
      WRITE(12,32)BFL,TGC,VIS,DEP,DH,CFT,SLP,VEL,RAD,SHE,FRC,REY
```

```
     &,RAT,FRW,FRB,RBC,SHB,BST,WST
  32  FORMAT(//' SIDE-WALL CORRECTION PARAMETERS:'//
     &' CHANNEL WIDTH                   BFL=',F12.3,' METER'/
     &' TEMPERATURE                     TGC=',F10.1,' CELSIUS DEG.'/
     &' VISCOSITY                       VIS=',E16.3,' SQ.METERS/SEC.'/
     &' DEPTH                           DEP=',F13.4,' METER'/
     &' DISCHARGE MANOMETER READING     DH =',F13.4,' METER (OF HG)'/
     &' DISCHARGE                       QFI=',F14.5,' CUB.METERS/SEC.'/
     &' ENERGY SLOPE                    SLP=',F16.7/
     &' MEAN VELOCITY                   VEL=',F13.4,' METERS/SEC.'/
     &' HYDRAULIC RADIO                 RAD=',F13.4,' METER'/
     &' SHEAR VELOCITY                  SHE=',F13.4,' METER/SEC.'/
     &' DARCY-WEISBACH FRICT.COEFF.     FRC=',F13.4/
     &' REYNOLDS NUMBER                 REY=',E16.3/
     &' REY/FRC RATIO                   RAT=',E16.3/
     &' WALL-FRICTION COEFF.            FRW=',F13.4/
     &' BED-FRICTION COEFF.             FRB=',F13.4/
     &' BED HYDRAULIC RADIO             RBC=',F13.4,' METER'/
     &' BED SHEAR VELOCITY              SHB=',F13.4,' METER/SEC.'/
     &' BED/GLOBAL STRESS RATIO         BST=',F11.2/
     &' WALL/GLOBAL STRESS RATIO        WST=',F11.2)
C-- COMPUTE Y+ AND U+
      YP=SHB/VIS*.001
      UP=1./SHB
      DO 35 I=1,N
      G(I)=Y(I)*YP
      Z(I)=DLOG(G(I))
  35  F(I)=U(I)*UP
      YP=YP*1000.
      DP=DEP
      RETURN
      END
C=====================================================================
      SUBROUTINE MFLOW(SHB,VIS,SLP,GRA,FDW,UA,UAP,DEP,A,C,M,N,IP,GA,WG
     &,NU,YMI,ZMI)
C     COMPUTE MEAN VELOCITY UA BY INTEGRATING THE BEST REGRESSION
C     POLYNOMIAL, AND COMPUTE DARCY-WEISBACH FRICTION COEFFICIENT FDW
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON KI5,KO3,IAP
      DIMENSION C(M),GA(NU),WG(NU)
      YMA=DEP*SHB/VIS
      YTP=YMA-YMI
      YTM=YTP*.5
      SUM=FREG1(ZMI,A,C,M,IP)*YMI*.5
      DO 10 I=1,NU
      Z=DLOG((1.+GA(I))*YTM+YMI)
  10  SUM=SUM+WG(I)*FREG1(Z,A,C,M,IP)*YTM
      UAP=SUM/YMA
      FDW=8./UAP**2
      UA=UAP*SHB
      WRITE(12,100)UA,UAP,FDW
      WRITE(KO3,100)UA,UAP,FDW
 100  FORMAT(/80('=')/' FLOW RESISTANCE CALCULATIONS FROM REGRESSION'
     &/'  MEAN VELOCITY            UA  = ',F12.3,' M./SEC.'
     &/'  DIMENSIONLESS MEAN       UA+ = ',F12.3
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```
     &/'  DARCY-WEISBACH COEFF.     FDW = ',F12.3/)
      RETURN
      END
C======================================================================
    . SUBROUTINE KARMAN(Y,U,G,Z,F,B,E,M,N,DP,VP,H,S,C,YP,UP,YMA,VMA,A,R
     &,IPO,SHV,VIS,IFR,HF,MF,IOK,XX,YY,XR,YR,MD,LTT)
C-- PLOT FUNCTIONS UPON RELATIVE DEPTH OBTAINED IN ROUTINE ORIGIN
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 V4,V5,V6,XX,YY,XR,YR,X3,Y3,A3,XO,YO,AX,AY,XX1,XX2,YY1,YY2
     &,XB,YB,XS,YS,HF,XA,YA
C:::::   NEXT    1   LINES      NEEDED       FOR VS FORTRAN VERSION
      CHARACTER*4 L1A,L1B,L1,L2,L3,L4,L5,L6,L7,L8,L9,M2,M3,LT,LTT
      COMMON KI5,KO3,IAP
      DIMENSION Y(M),U(M),G(M),Z(M),F(M),B(M),E(M),S(M),C(M),H(M,M)
     &,L1(3),L2(1),L3(5),L4(2),L5(2),IPE(8),XX(MD),YY(MD),XR(MD),YR(MD)
     &,L6(2),LT(4),R(M),L7(2),L8(2),L9(7),IFR(M),HF(M,MF),XA(4),YA(4)
     &,M3(5,4),M2(1,4)
      DATA PIM/1.570796327D0/,L1/'    ','LN(H','/D) '/,XA,YA/1.,8.,1.,8.
     &,6.,6.,1.,1./,M2/'V.K.',' AP','EPS+',' PI'/,M3/' KAR','MAN '
     &,'COEF','FICI','ENT ','    ','INTE','RCEP','T   ','    ',' ',' VI'
     &,'RTUA','L  O','RIGI','N   ','    ','WAKE',' STR','ENGT','H   '/
     &,IPE/1,2,3,4,5,6,7,8/,I1,I2,I3,IP/3,1,5,8/,X3,Y3,A3/4.,7.2,0./
     &,AX,AY/6.,4./,JX,JY,IX,IY,KX,KY/0,0,2,2,3,3/,I6,I7/2,2/,L4,L5,L6/
     &',  V','K = ',' , A','P = ',' , E','+ = '/,I4,I5/2,2/,LT/'CASE'
     &,' NUM','BER ','    '/,L7/'   U','* = '/,IT,I8,I9/4,2,7/,L8/' VIS'
     &,'C.= '/,L9/'( VA','LUES',' IN ','MM. ','AND ','SEC.',')   '/
C-- DEFINE PLOTTING PARAMETERS
    3 LT(IT)=LTT
      WRITE(KO3,1)
    1 FORMAT(/60('-')/' TO PLOT FUNCTIONS UPON RELATIVE DEPTH, '
     &/10X,'ENTER 1 (PEN PLOTTER) OR 2 (TEKTRONIX) OR 3 (VERSATEC)'
     &/' OTHERWISE,  ENTER 0  :')
      READ(KI5,2)IPL
      IF(IPL.EQ.3)IAP=1
    2 FORMAT(I1)
C-- OPTIONAL PLOTTING
      IF(IPL.EQ.0)RETURN
      WRITE(12,4)IOK
    4 FORMAT(/80('=')/' PLOT OF FUNCTIONS UPON RELATIVE DEPTH'
     &/' FOR ',I5,' DATA POINTS'/)
C:::::   NEXT    1   LINES    NEEDED       FOR CALCOMP LIBRARY
      CALL PLO(IPL,1,C)
C:::::   NEXT    1   LINES    NEEDED       FOR HP-ISPP LIBRARY
C     CALL HPINIT(1,0,0,0,20)
      CALL NEWPEN(IPE(3))
      CALL SYMBOL(1.5,6.3,.14,LT,0.,4*IT)
      JJ=7
      DO 80 ICA=1,4
      JJ=JJ+1
      DO 11 I=1,IOK
      XX(I)=ALOG(HF(I,7))
      Y(I)=XX(I)
      XR(I)=XX(I)
      YY(I)=HF(I,JJ)
   11 U(I)=YY(I)
```

```
      WRITE(12,20)ICA,(M3(I,ICA),I=1,5)
   20 FORMAT(//'===>>',I3,'A):  ',5A4)
      CALL BSTREG(6,M,Y,U,IOK,A,C,B,E,F,G,H,IC,Z,S,SD,1,1)
      CALL LIMITS(XX1,XX2,YY1,YY2,XX,YY,MD,IOK)
      XO=XA(ICA)
      YO=YA(ICA)
      X3=XO+2.
      Y3=YO+AY+.15
      DO 12 I=1,5
   12 L3(I)=M3(I,ICA)
      DO 13 I=1,IOK
   13 YR(I)=FREG1(Y(I),A,B,M,IC)
      L2(1)=M2(1,ICA)
   80 CALL HPLOT2(-1,1,L1,I1,L2,I2,L3,I3,X3,Y3,A3,IPE,IP,XX,YY,XR,YR
     &,MD,IOK,XO,YO,AX,JX,KX,AY,JY,KY,IX,XX1,XX2,IY,YY1,YY2
     &,LT,IT,XS,YS,L7,I7,SHV,L8,I8,VIS,L9,I9,V6,XB,YB, 0)
      CALL PLC(IPL,2,15)
      GO TO 3
      END
C=====================================================================
      SUBROUTINE DEFECT(Y,U,G,Z,F,B,E,M,N,DP,VP,H,S,C,YP,UP,YMA,VMA,A,R
     &,IPO,VK,AB,PI,IFR,HF,MF,IOK,XX,YY,XR,YR,MD,LTT,JOK)
C-- PLOT LAWS OF THE WALL, THE WAKE AND VELOCITY-DEFECT LAW (FROM BED)
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 V4,V5,V6,XX,YY,XR,YR,X3,Y3,A3,XO,YO,AX,AY,XX1,XX2,YY1,YY2
     &,XB,YB,XS,YS,HF,XA,YA
C:::::   NEXT    2    LINES       NEEDED        FOR VS FORTRAN VERSION
      CHARACTER*4 L1,L2,L3,L4,L5,L6,L7,L8,L9,M2,M3,LT,LTT,LA,LB,LC,LTB
     &,L1A,L1B
      COMMON KI5,KC3,IAP
      DIMENSION Y(M),U(M),G(M),Z(M),F(M),B(M),E(M),S(M),C(M),H(M,M)
     &,L1(3),L2(1),L3(5),L4(4),L5(4),IPE(8),XX(MD),YY(MD),XR(MD),YR(MD)
     &,L6(4),LT(4),R(M),IFR(M),HF(M,MF),XA(4),YA(4),L7(4),L8(4),L9(4)
     &,M3(5,4),M2(1,4),JOK(4),IOQ(6),IUC(6),KTQ(6),LA(4),LB(4),LC(4)
     &,LTB(2),L1A(3),L1B(3),JJJ(4)
      DATA PIM/1.5707963270D0/,L1A/'    ','  LN','(Y+)'/,XA,YA/1.,8.,1.
     &,8.,2*6.,2*1./,M2/'  U+',' D+ ','  U+','   W'/,M3/'VELO','C. D'
     &,'ISTR','IBUT','ION ','VEL.','-DEF','ECT ','DIST','RIB.' ,'LOG.'
     &,' LAW',' OF ','THE ','WALL','  WA','KE  ','FUNC','TION','S   '/
     &,IPE/1,2,3,4,5,6,7,8/,I1,I2,I3,IP/3,1,5,8/,X3,Y3,A3/4.,7.2,0./
     &,AX,AY/6.,4./,JX,JY,IX,IY,KX,KY/0,0,2,2,3,3/,L4/'MEAS','URED'
     &,' WAK','E   '/,L5/'COLE','S FU','NCTI','ON  '/,L6/'FINL','EY F'
     &,'UNCT','ION '/,IT,I4,I5,I6/4*4/,LT/'CASE',' NUM','BER ','    '/
     &,IOQ/3*0,1,2,3/,IUC/4*1,2*2/,KTQ/2*-1,-2,4,5,6/,XB,YB/4.7,1.7/
     &,L7/'  VO','N KA','RMAN',' =  '/,L8/'   I','NTER','CEPT',' = '/
     &,L9/'WAKE',' STR','ENGT','H = '/,LTB/'FROM',' BED'/,IB/2/
     &,JJJ/13,20,2*13/,L1B/'    ',' LN(','Y/D)'/
      V4=VK
      V5=AB
      V6=PI
C-- DEFINE PLOTTING PARAMETERS
      LT(IT)=LTT
    3 WRITE(KC3,1)
    1 FORMAT(/' LAWS OF THE WALL AND THE WAKE AND VELOCITY-DEFECT LAW :'
     &/' ENTER 1 (PEN PLOTTER) OR 2 (TEKTRONIX)  OR 3 (VERSATEC)'
```

```
     &/' OTHERWISE,  ENTER 0  :')
      READ(KIS,2)IPL
    2 FORMAT(I1)
      IF(IPL.EQ.3)IAP=I
C-- OPTIONAL PLOTTING
      IF(IPL.EQ.0)RETURN
      WRITE(12,4)JOK(1)
    4 FORMAT(/80('=')/' PLOT OF FUNCTIONS WITH Y+ COMPUTED FROM 3ED'
     &/' FOR ',I5,' DATA POINTS'/)
C:::::   NEXT   1   LINES   NEEDED      FOR CALCOMP LIBRARY
      CALL PLC(IPL,1,C)
C:::::   NEXT   1   LINES   NEEDED      FOR HP-ISPP LIBRARY
C     CALL HPINIT(1,0,C,0,20)
      CALL NEWPEN(IPE(3))
      CALL SYMBOL(1.5,9.6,.14,LT,0.,4*IT)
      JJ=JJJ(1)
      DO 80 JCA=1,6
      ICA=MINO(JCA,4)
      IOK=JOK(ICA)
      JJ=JJ+1
      KK=JJJ(ICA)
      DO 11 I=1,ICK
      XX(I)=HF(I,KK)
      Y(I)=XX(I)
      XR(I)=XX(I)
      YY(I)=HF(I,JJ)
   11 U(I)=YY(I)
      N=MINO(ICK-2,8)
      GO TO(12,14,12,16,24,24),JCA
   12 DO 13 I=1,3
   13 L1(I)=L1A(I)
      GO TO 16
   14 DO 15 I=1,3
   15 L1(I)=L1B(I)
   16 WRITE(12,20)ICA,(M3(I,ICA),I=1,5)
   20 FORMAT(//'===>>',I3,'B):   ',5A4)
      CALL BSTREG(6,M,Y,U,ICK,A,C,B,E,F,G,H,IC,Z,S,SD,1,1)
   24 CALL LIMITS(XX1,XX2,YY1,YY2,XX,YY,MO,ICK)
      XO=XA(ICA)
      YO=YA(ICA)
      X3=XO+2.
      Y3=YO+AY+.15
      GO TO(40,40,33,36,80,80),JCA
   33 DO 34 I=1,4
      LA(I)=L7(I)
      LB(I)=L8(I)
   34 LC(I)=L9(I)
      XS=1.5
      YS=4.5
      GO TO 40
   36 DO 38 I=1,4
      LA(I)=L4(I)
      LB(I)=L5(I)
   38 LC(I)=L6(I)
      XS=8.5
```

```
      YS=4.5
   40 DO 42 I=1,5
   42 L3(I)=M3(I,ICA)
      DO 43 I=1,IOK
   43 YR(I)=FREG1(Y(I),A,B,M,IC)
      L2(1)=M2(1,ICA)
   80 CALL HPLOT2(K1C(JCA),IUQ(JCA),L1,I1,L2,I2,L3,I3,X3,Y3,A3,IPE,IP
     &,XX,YY,XR,YR,MD,IOK,XO,YO,AX,JX,KX,AY,JY,KY,IX,XX1,XX2,IY,YY1
     &,YY2,LTB,IB,XS,YS,LA,I4,V4,LB,I5,V5,LC,I6,V6,XB,YB,IOC(JCA))
      CALL PLO(IPL,2,15)
      GO TO 3
      END
C=====================================================================
      SUBROUTINE ORIGIN(Y,U,G,Z,F,B,E,M,N,DF,VP,H,S,C,YP,UP,YMA,VMA,A,R
     &,IPO,SHV,VIS,IFR,HF,MF,IOK,XX,YY,XR,YR,MD,LTT,JOK,VKA,AB,PIA)
C-- FIND VIRTUAL ORIGIN DISTANCE
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*4 V4,V5,V6,XX,YY,XR,YR,X3,Y3,A3,XO,YO,AX,AY,XX1,XX2,YY1,YY2
     &,XB,YB,XS,YS,HF
C::::: NEXT    1   LINES      NEEDED        FOR VS FORTRAN VERSION
      CHARACTER*4 L1,L1C,L2,L3,L3D,L4,L5,L6,L7,L8,L9,M2,M3,LT,LTT
      COMMON KI5,KO3,IAP
      DIMENSION Y(M),U(M),G(M),Z(M),F(M),B(M),E(M),S(M),C(M),H(M,M)
     &,L1(3),L2(3),L3(5),L4(2),L5(2),IPE(8),XX(MD),YY(MD),XR(MD),YR(MD)
     &,L6(2),LT(4),R(M),L7(2),L8(2),L9(7),IFR(M),HF(M,MF),L3D(5,2)
     &,L1D(3,2),JOK(4)
      DATA PIM/1.570796327D0/,L1D/'LN(Y','+ + ','E+) ','2X-T','ANH*'
     &,'-1 X'/,XO,YO/1.,1./,L2/'    ','    ','  U+'/,L3D/'U+  ','VS. '
     &,' LN(','Y+ +',' E+)','U+ V','S. 2','X-TA','NH*-','1(X)'/
     &,IPE/1,2,3,4,5,6,7,8/,I1,I2,I3,IP/3,3,5,8/,X3,Y3,A3/4.,7.2,0./
     &,AX,AY/8.,6./,JX,JY,IX,IY,KX,KY/0,0,2,2,3,3/,I6,I7/2,2/
     &,L4,L5,L6/',  V','K = ',' , A','P = ',' , E','+ = '/,I4,I5/2,2/
     &,LT/'CASE',' NUM','BER ','    '/,L7/'   U','* = '/,IT,I8,I9/4,2,7/
     &,L8/' VIS','C.= '/,L9/'( VA','LUES',' IN ','MM. ','AND ','SEC.'
     &,')   '/,RER/10.D0/
C-- DEFINE PLOTTING PARAMETERS
      IUS=0
      N1=N
   10 ICK=0
      PER=0.
      WRITE(KO3,1)
    1 FORMAT(/' TO PLOT THE VIRTUAL-ORIGIN SEARCH'
     &/' ENTER 1 (PEN PLOTTER) OR 2 (TEKTRONIX)  OR 3 (VERSATEC)'
     &/' OTHERWISE,  ENTER 0  :')
      READ(KI5,86)IPL
      IF(IPL.EQ.3)IAP=1
C-- NEXT 4 LINES ARE FOR FUTURE DEVELOPMENT
C     WRITE(KO3,40)
C 40  FORMAT(/' ENTER LAW :  1 = "LN TYPE" ,  2 = "TANH TYPE"')
C     READ(KI5,86)LAW
C     IF(LAW.LT.1.OR.LAW.GT.2)LAW=1
      LAW=1
      IF(IUS.NE.0)GO TO 2
      IUS=1
      WRITE(KO3,4)
```

```
    4   FORMAT(/' ENTER CASE NUMBER (UP TO FOUR FIGURES): ')
        READ(KI5,5)LT(IT)
        WRITE(12,89)LT(IT)
   89   FORMAT(/10X,' ****************************************'/
      &         10X,' ***                                  ***'/
      &         10X,' ***          CASE NUMBER ',A4,5X,'       ***'/
      &         10X,' ***                                  ***'/
      &         10X,' ****************************************'/)
        LTT=LT(IT)
    5   FORMAT(A4)
        ZP=DLOG(DP)
        VP=FREG1(ZP,A,R,M,IPO)
        VMA=FREG1(DLOG(YMA),A,R,M,IPO)
        WRITE(12,84)LT(IT),(I,G(I),Z(I),F(I),I=1,N)
        WRITE(12,88)DP,ZP,VP
        IF(N.EQ.M)GO TO 2
        N=N+1
        G(N)=DP
        Z(N)=ZP
        F(N)=VP
        WRITE(KO3,91)N,YMA,VMA
        WRITE(12,91)N,YMA,VMA
    2   KAN=0
        XS=XO+.3
        YS=YO+AY-.3
        XB=.65*AX+XO
        YB=.7+YO
C-- OPTIONAL PLOTTING WITH "HP-ISPP,HP 17580B"(OR CALCOMP)
        IF(IPL.EQ.0)GO TO 3
C:::::   NEXT    1   LINES   NEEDED      FOR CALCOMP LIBRARY
        CALL PLO(IPL,1,C)
C:::::   NEXT    1   LINES   NEEDED      FOR HP-ISPP LIBRARY
C       CALL HPINIT(1,C,C,C,20)
        DO 6 I=1,N
        GO TO(41,42),LAW
C-- LOG LAW
   41   XX(I)=DLOG(G(I))
        GO TO 43
C-- TANH LAW
   42   HF(I,1)=G(I)/YMA
        FUX=SQRT(1.-HF(I,1))
        EA=DEXP(FUX)
        EB=DEXP(-FUX)
        XX(I)=FUX+FUX-(EA-EB)/(EA+EB)
        HF(I,2)=FUX
C-- ANY LAW
   43   YY(I)=F(I)
        XR(I)=XX(I)
        XRI=DLOG(G(I))
    6   YR(I)=FREG1(XRI,A,R,M,IPO)
        CALL LIMITS(XX1,XX2,YY1,YY2,XX,YY,MD,N)
        DO 57 I=1,I3
   57   L3(I)=L3D(I,LAW)
        DO 58 I=1,I1
   58   L1(I)=L1D(I,LAW)
```

```
      CALL HPLOT2(0,1,LI,II,L2,I2,L3,I3,X3,Y3,A3,IPE,IP,XX,YY,XR,YR
     C,MD,N,XO,YO,AX,JX,KX,AY,JY,KY,IX,XX1,XX2,IY,YY1,YY2
     C,LT,IT,XS,YS,L7,I7,SHV,L8,I8,VIS,L9,I9,V6,XB,YB, 1)
C-- SEARCH OF VIRTUAL ORIGIN BEGINS HERE
    3 PER=PER+1.
      DPM=PER*.01*YMA
      DO 12 I=1,N
      IF(G(I).GT.DPM)GO TO 14
   12 CONTINUE
   14 NI=I-1
      IF(NI.EQ.NI)GO TO 11
C-- IF NI HAVE BEEN TESTED GO FOR OTHER NI VALUE
      IF(NI.LE.3.OR.IFR(NI).EQ.1)GO TO 3
   11 IFR(NI)=1
C-- INITIALIZATE SEARCH PARAMETERS
      LK=2
      IF(NI.GE.NI)LK=3
      TOE=1.E-6
      SC=1.E10
      DP1=.001*YP
      EP1=DP1
      JET=0
      ICO=0
C-- SEARCH FOR NULL SECOND REGRESS. COEFF. IN A 2ND-ORDER REGRESS.
C   FOR DIFFERENT VIRTUAL DISTANCES
   50 DO 55 J=1,999
      EP1=EP1+DP1
      DEL=YMA+EP1
      DO 52 I=1,NI
      GGG=G(I)+EP1
      IF(GGG.LE.0.)GO TO 61
      GO TO(21,22),LAW
C-- LOG LAW
   21 C(I)=DLOG(GGG)
      GO TO 52
C-- TANH LAW
   22 HF(I,1)=GGG/DEL
      FUX=SQRT(ABS(1.-HF(I,I)))
      EA=DEXP(FUX)
      EB=DEXP(-FUX)
      C(I)=2.*FUX-(EA-EB)/(EA+EB)
      HF(I,2)=FUX
   52 CONTINUE
      SDE=REGRE1(NI,C,F,2,AL,B,M,M,M,M,E,Z,S,H,0,1.D-30)
      JET=JET+1
      IF(B(2)*(SC-B(2)).LE.0.)GO TO 60
   54 SC=B(2)
   55 AA=AL
C-- CHECK FOR CONVERGENCE AND EVENTUALLY CHANGE DIRECTION OF SEARCH
   60 SC=B(2)
      IF(DABS(SC).LE.TOE)GO TO 70
      ICO=ICO+1
      IF(ICO.GE.500)GO TO 62
      IF(DABS(DP1).GT.1.D-10)DP1=-DP1*.4
      GO TO 50
```

```
 61   DP1=DABS(DP1)
      GO TO 50
C-- ON FAILURE TRY OTHER SET OF POINTS
 62   WRITE(12,64)ICO,JET,SC,B(2),DP1,EP1
 64   FORMAT(' UNSOLVED:I,J,SC,B2,D,E=',2I4,4E11.3)
      GO TO 3
C-- ON SUCCESS, GET LINEAR REGRESSION, KARMAN COEFFICIENT, INTERCEPT
C    WAKE STRENGTH, COLES' AND FINLEY'  WAKE FUNCTIONS , ETC
 70   YMX=YMA+EP1
      SDE=REGRE1(NI,C,F,1,AA,B,M,M,M,M,E,Z,S,H,0,1.D-20)
      IF(SDE.EQ.0.)GO TO 62
      EPS=EP1/YP
      VK=1./B(1)
      GO TO(31,32),LAW
C-- LOG LAW
 31   PIW=.5*(VK*(VMA-AA)-DLOG(YMX))
      FIN=VK/PIW
      DO 72 I=1,N
      C(I)=G(I)+EP1
      Z(I)=DLOG(C(I))
      H1=C(I)/YMX
      HF(I,1)=H1
      HF(I,2)=DLOG(H1)
      HF(I,3)=F(N)-F(I)
      HF(I,4)=(F(I)-Z(I)/VK-AA)*FIN
      HF(I,5)=2.*DSIN(PIM*H1)**2
 72   HF(I,6)=((6.-FIN-4.*H1)*H1+FIN)*H1
      WRITE(12,83)NI,PER,SDE,SC,EPS,EP1,AA,VK,PIW,YMX,VMA
      WRITE(12,90)(I,C(I),Z(I),F(I),(HF(I,K),K=1,6),I=1,N)
C     WRITE(16,23)LAW,N,NI,PER,SDE,EP1,AA,VK,PIW,YMX,VMA
C    &             ,(I,C(I),Z(I),F(I),(HF(I,K),K=1,6),I=1,N)
 23   FORMAT(3I5/4F14.5/4F14.5/(I5,F10.3,8F8.3))
      GO TO 71
C-- TANH LAW
 32   WRITE(12,87)NI,PER,SDE,SC,EPS,EP1,AA,VK,YMX,VMA
      WRITE(12,92)(I,HF(I,1),HF(I,2),C(I),F(I),I=1,N)
C     WRITE(16,24)LAW,N,NI,PER,SDE,EP1,AA,VK,DEL,YMX,VMA
C    &             ,(I,HF(I,1),HF(I,2),C(I),F(I),I=1,N)
 24   FORMAT(3I5/4F14.5/4F14.5/(I5,4F12.4))
 71   IOK=IOK+1
      HF(IOK,7)=G(NI)/G(N)
      HF(IOK,8)=VK
      HF(IOK,9)=AA
      HF(IOK,10)=EP1
      HF(IOK,11)=PIW
      HF(IOK,12)=NI
      IF(IPL.LE.0)GO TO 75
      DO 73 I=1,NI
      XR(I)=Z(I)
      YR(I)=FREG1(Z(I),AA,B,M,1)
      XX(I)=Z(I)
 73   YY(I)=F(I)
      KAN=KAN+1
      IF(KAN.EQ.7)LK=3
      V4=VK
```

```
      V5=AA
      V6=EP1
      CALL HPLOT2(3,1,L1,I1,L2,I2,L3,I3,X3,Y3,A3,IPE,IP,XX,YY,XR,YR
     &,MD,NI,XO,YO,AX,JX,KX,AY,JY,KY,IX,XX1,XX2,IY,YY1,YY2
     &,LT,IT,XS,YS,L4,I4,V4,L5,I5,V5,L6,I6,V6,0.,0.,LK)
      IF(LK.EQ.3)CALL FLO(IPL,2,12)
   75 IF(LK.EQ.2)GO TO 3
      WRITE(KO3,93)
      IF(NI.LT.N1)WRITE(KO3,94)NI,N1
      WRITE(KO3,95)
      READ(KI5,86)K
      IF(K.EQ.0)GO TO 59
      IF(K.EQ.1.AND.NI.LT.N1)GO TO 2
      DO 74 K=4,N
   74 IFR(K)=0
      GO TO 10
C-- COMPUTE DISTRIBUTIONS FOR NULL VIRTUAL ORIGIN
   59 DPM=RER*.01*YMA
      DO 44 I=1,N
      IF(G(I).GT.DPM)GO TO 45
   44 CONTINUE
   45 NJ=I-1
      DO 48 I=1,N
   48 C(I)=DLOG(G(I))
      SDJ=REGRE1(NJ,C,F,1,AB,B,M,M,M,M,E,Z,S,H,0,1.D-20)
      VKA=1./B(1)
      PIA=.5*(VKA*(VMA-AB)-DLOG(YMA))
      FIN=VKA/PIA
      DO 46 I=1,N
      H1=G(I)/YMA
      HF(I,13)=C(I)
      HF(I,14)=F(I)
      HF(I,15)=VMA-F(I)
      HF(I,16)=F(I)
      HF(I,17)=(F(I)-C(I)/VKA-AB)*FIN
      HF(I,18)=2.*DSIN(PIM*H1)**2
      HF(I,19)=((6.-FIN-4.*H1)*H1+FIN)*H1
   46 HF(I,20)=H1
      WRITE(12,47)NJ,RER,SDJ,AB,VKA,PIA,YMA,VMA
     &,(I,G(I),C(I),F(I),HF(I,15),(HF(I,K),K=17,19),I=1,N)
      JOK(1)=N
      JOK(2)=N
      JOK(3)=NJ
      JOK(4)=N
      RETURN
   47 FORMAT(/79('-')/' LAW TYPE 1 , U+.VS.LN(Y+) FOR NULL VIRTUAL OR'
     &,'IGIN'/' USING',I4,' POINTS ( PER =',F8.2,' % OF B.LAYER )'
     &/' STANDARD ERROR OF ESTIMATE   SE  =',E12.3
     &/' INTERCEPT                    AP  =',F12.3,' ( IN U+ COORD.)'
     &/' KARMAN COEFFICIENT           VK  =',F12.3
     &/' WAKE STRENGTH                PI  =',F12.3
     &/' BOUNDARY LAYER THICKNESS     D+  =',F12.3,' ( IN Y+ COORD.)'
     &/' REFERENCE FLOW VELOCITY      VM+ =',F12.3,' ( IN U+ COORD.)'/
     &/4X,'I',8X,'Y+',4X,'LN(Y+)',8X,'U+',7X,'DU+',6X,'WAKE',5X
     &,'COLES',4X,'FINLEY'/(I5,7F10.3))
```

```
 83  FORMAT(/79('-')/' LAW TYPE 1 : LN(Y+)'/' USING',I4
    &,' POINTS ( PER =',F8.2,' % OF B.LAYER )'
    &/' STANDARD ERROR OF ESTIMATE   SE  =',E12.3
    &/' 2ND.-ORDER REGR.COEFF.       B(2)=',E12.3
    &/' VIRTUAL ORIGIN DISTANCE      EPS =',F12.5,' ( IN METERS )'
    &/' VIRTUAL ORIGIN DISTANCE      EP+ =',F12.3,' ( IN Y+ COORD.)'
    &/' INTERCEPT                    AP  =',F12.3,' ( IN U+ COORD.)'
    &/' KARMAN COEFFICIENT           VK  =',F12.3
    &/' WAKE STRENGTH                PI  =',F12.3
    &/' BOUNDARY LAYER THICKNESS     D+  =',F12.3,' ( IN Y+ COORD.)'
    &/' REFERENCE FLOW VELOCITY      VM+ =',F12.3,' ( IN U+ COORD.)')
 84  FORMAT(/' VALUES BEFORE ORIGIN CORRECTION FOR THE CASE NUMBER ',A4
    &/' LAW-OF-THE-WALL COORDINATES Y+ AND U+'/' (LAST VALUE '
    &,'CORRESPONDS TO THE DEPTH )'/4X,'I',13X,'Y+',6X,'LN(Y+)',10X
    &,'U+'/(I5,F15.3,2F12.3))
 85  FORMAT(/' ======>> TO CONTINUE,  ENTER 0 ')
 86  FORMAT(I1)
 87  FORMAT(/79('-')/' LAW TYPE 2 : 2X - TANH**-1(X)'/' USING',I4
    &,' POINTS ( PER =',F8.2,' % OF B.LAYER )'
    &/' STANDARD ERROR OF ESTIMATE   SE  =',E12.3
    &/' 2ND.-ORDER REGR.COEFF.       B(2)=',E12.3
    &/' VIRTUAL ORIGIN DISTANCE      EPS =',F12.5,' ( IN METERS )'
    &/' VIRTUAL ORIGIN DISTANCE      EP1 =',F12.3,' ( IN Y+ COORD.)'
    &/' INTERCEPT                    AP  =',F12.3,' ( IN U+ COORD.)'
    &/' KARMAN COEFFICIENT           VK  =',F12.3
    &/' BOUNDARY LAYER THICKNESS     D+  =',F12.3,' ( IN Y+ COORD.)'
    &/' REFERENCE FLOW VELOCITY      VM+ =',F12.3,' ( IN U+ COORD.)')
 88  FORMAT(' SURFACE',3F12.3/)
 90  FORMAT(/' LAW TYPE 1 : VALUES AFTER ORIGIN CORRECTION:'
    &/4X,'I',6X,'Y+',5X,'LN(Y+)',3X,'U+',5X,'Y+/D+',2X,'LN(Y/D)',2X
    &,'UM-U+',4X,'WAKE',3X,'COLES',2X,'FINLEY'/(I5,F10.3,8F9.3))
 91  FORMAT(' SURFACE VALUES HAS BEEN ADDED TO Y+,U+ LAW AS THE POINT'
    &,' NUMBER',I5/
    &' BOUNDARY LAYER THICKNESS     D+  =',F12.3,' ( IN Y+ COORD.)'/
    &' REFERENCE FLOW VELOCITY      VM+ =',F12.3,' ( IN U+ COORD.)')
 92  FORMAT(/' LAW TYPE 2 : VALUES AFTER ORIGIN CORRECTION:'
    &/4X,'I',7X,'Y/D',9X,'X',4X,'FCT(X)',3X,'U+'/(I5,4F10.3))
 93  FORMAT(' IF YOU LIKE TO  RESTART THE ORIGIN SEARCH, ENTER 2 ')
 94  FORMAT(' IF YOU LIKE TO CONTINUE THE ORIGIN SEARCH, ENTER 1 '
    &      /' ( LAST NI =',I3,' : MAX.NI =',I3,' )')
 95  FORMAT(' OTHERWISE,  ENTER 0 ')
     END
C=====================================================================
     SUBROUTINE LIMITS(X1,X2,Y1,Y2,X,Y,M,N)
C-- FIND PLOTTING LIMITS
     DIMENSION X(M),Y(M)
     X1=1.09
     X2=-1.09
     Y1=1.09
     Y2=-1.09
     DO 1 I=1,N
     IF(X(I).LT.X1)X1=X(I)
     IF(X(I).GT.X2)X2=X(I)
     IF(Y(I).LT.Y1)Y1=Y(I)
 1   IF(Y(I).GT.Y2)Y2=Y(I)
```

```
      DX=.05*(X2-X1)
      DY=.05*(Y2-Y1)
      X1=FLOAT(IFIX((X1-DX)*10.-1.))*.1
      X2=FLOAT(IFIX((X2+DX)*10.+1.))*.1
      Y1=FLOAT(IFIX((Y1-DY)*10.-1.))*.1
      Y2=FLOAT(IFIX((Y2+DY)*10.+1.))*.1
      RETURN
      END
C====================================================================
      SUBROUTINE PLO(I,J,N)
      DATA NPL/999/
C::::: NEXT LINE        NEEDED FOR  HP-ISPP  VERSION
C     CALL PLOT(0.,0.,999)
C::::: NEXT BLOCK       NEEDED FOR  CALCOMP  VERSION
      GO TO(10,20,30),I
C-- OPEN 8-PEN PLOTTER        (I=1,J=1)
  10  GO TO(1,2,3),J
   1  CALL PLOTS(IBUFF,18000,6)
      CALL PLINIT(1)
      CALL PLON
      CALL PLCOPY(1)
      CALL SWCHAR(1)
      CALL PEN(N)
      RETURN
C-- CLOSE 8-PEN PLOTTER       (I=1,J=2)
   2  CALL PEN(0)
      CALL PLOFF
      RETURN
C-- CHANGE PEN                (I=1,J=3)
   3  CALL PEN(0)
      CALL PEN(N)
      RETURN
C-- OPEN PLOT ON SCREEN       (I=2,J=1)
  20  GO TO(6,7,8),J
   6  CALL PLOTS(0,0,1)
      RETURN
C-- CLOSE PLOT ON SCREEN      (I=2,J=2)
   7  CALL PLOT(0.,0.,999)
   8  RETURN
C-- OPEN VERSATEC PLOTTER     (I=3,J=1)
  30  GO TO(31,32,33),J
  31  IF(NPL.NE.999)RETURN
      CALL PLOTS(0,0,6)
      CALL PLOT(0,0,-3)
      NPL=0
      RETURN
C-- CLOSE VERSATEC PLOTTER    (I=3,J=2,N=999)
  32  IF(N.NE.999)GO TO 33
      CALL PLOT(0.,0.,999)
      RETURN
C-- NEXT VERSATEC PAGE        (I=3,J=3)  OR (I=3,J=2,N=0)
  33  CALL PLOT(FLOAT(N),0.,-3)
C::::: PREVIOUS  BLOCK        NEEDED FOR  CALCOMP  VERSION
      RETURN
      END
```

```
C=====================================================================
      SUBROUTINE SCALE1(T,PE,JP,NTC,IO,TA,TB,AT)
C-- PLOTTING AUXILIAR: SCALE T(I)
C  .T IS THE VECTOR TO SCALE AND SCALED VALUES ON RETURN
C          T(JP+1)=FIRST VALUE IN THE AXIS,T(JP+2)=INCREMENT PER INCH
C  .PE IS THE LENGTH OF PLOTTING IN INCHES
C  .JP IS THE NUMBER OF POINTS, NTC IS THE DIMENSION OF T (NTC>JP+1)
C  .OPTION IO=1: SCALE T(JP) BETWEEN MIN(T)-TA AND MAX(T)+TB
C          IO=2: SCALE T(JP) BETWEEN MIN(T,TA) AND MAX(T,TB)
C  .AT IS ADDED TO SCALED VALUES (TO ACCOUNT FOR FRAME POSITIONING)
C---------------------------------------------------------------------
      DIMENSION T(NTC)
      DATA AA,BB/1.E7,-1.E7/,CC/1.E-7/
C-- IDENTIFY MIN(T) AND MAX(T)
      A=AA
      B=BB
      DO 10 I=1,JP
      IF(T(I).GT.B)B=T(I)
   10 IF(T(I).LT.A)A=T(I)
      GO TO(11,12),IO
C-- OPTION IO=1
   11 B=B+TB
      A=A-TA
      GO TO 20
C-- OPTION IO=2
   12 A=AMIN1(A,TA)
      B=AMAX1(B,TB)
C-- SCALING...
   20 F=PE/AMAX1(B-A,CC)
      DO 30 I=1,JP
   30 T(I)=(T(I)-A)*F+AT
      T(JP+1)=A
      T(JP+2)=(B-A)/AMAX1(PE,CC)
      RETURN
      END
C=====================================================================
      SUBROUTINE HPLOT2(KT,KU,L1,I1,L2,I2,L3,I3,X3,Y3,A3,IPE,IP,X,Y,U,V
     &,M,N,XO,YO,AX,JX,KX,AY,JY,KY,IX,XMI,XMA,IY,YMI,YMA
     &,LT,IT,XS,YS,L4,I4,V4,L5,I5,V5,L6,I6,V6,XB,YB,IO)
C-- PLOTTING A GRAPH WITH HP-ISPP
C  KT:WRITE "N POINTS, (0=SUB-TITLE", 1=V4", 2=V4,V5", 3=V4,V5,V6")
C     =4,5,6 WRITE L4,L5,L6          (ON XS,YS AND BELOW POSITIONS)
C   (>=0, ALSO WRITE AS 2 ON XB,YB & L6, =-1, DO NOT, =-2, A3 ON XB,YB)
C  KU:SWITCH (0=SYMBOLS ONLY(X,Y), 2=CURVE THROUGH SYMBOLS (X,Y)
C        , 1=SYMBOLS(X,Y) AND CURVE(U,V), 3=CURVE(X,Y), 4=CURVE(U,V) )
C  L1(I1),L2(I2):AXIS' LABELS         ! L3(I3):TITLE
C  X3,Y3,A3:TITLE'S ORIGIN & ANGLE    ! IPE(IP):PEN'S ARRAY
C  X(M),Y(M):ORIGINAL DATA ARRAYS     ! N: NUMBER OF POINTS ( N < M-1 )
C  U(M),V(M):SECONDARY DATA ARRAYS (OFTEN CONTAINING A REGRESSION)
C  XO,YO:AXIS' ORIGIN                 ! AX,AY:AXIS' LENGTHS
C  JX,JY:AXIS' SWITCH FOR EXPONENTIAL NOTATION (1=YES,0=NO)
C  KX,KY:SWITCH FOR DIGITS (-1=INTEGER,0=DEC.POINT,KK=DIGITS PAST D.P.)
C  IX,XMI,XMA,IY,YMI,YMA:OPTIONS AND LIMITS FOR SCALE1 ROUTINE
C  LT(IT):SUB-TITLE, XS,YS:UPPER LEFT POSITION FOR SUB-TITLE AND LABELS
C  L4(I4),L5(I5),L6(I6) LABELS FOR V4,V5,V6 FOR EACH CURVE (KU=1 ONLY)
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C  BUT: L4(I4),L5(I5),L6(I6) LABELS FCR V4,V5 FOR CHART IDENTIFIER (KT=0
C  XB,YB:UPPER LEFT PCSITICN FOR CHART IDENTIFIERS (WHEN KT=0)L4,L5,L6
C  IO:SWITCH (=1 CPEN AND PLOT; =2 PLOT; =3 PLOT AND CLCSE; =0 ALL )
C-----------------------------------------------------------------------
C:::::   NEXT    1   LINES      NEEDED       FOR VS FCRTRAN VERSICN
      CHARACTER*4 L1,L2,L3,L4,L5,L6,LT,ISP,IMP
      DIMENSICN X(M),Y(M),U(M),V(M),L1(I1),L2(I2),L3(I3),IPE(IP),LA(15)
     &,LT(IT),ISP(1),IMP(2),LK(1),L4(I4),L5(I5),L6(I6)
      DATA KEY/0/,LA/0,1,2,3,4,5,9,10,11,12,14,6,7,8,13/
     &,H1,H2,H3,H4/.07,.1C,.18,.20/,ISP/'    '/,IMP/' PCI','NTS '/
      IF(IO.GT.1)GC TC 10
      K=1
      KEY=1
   10 IF(KEY.EQ.0)RETURN
      LK(1)=LA(K)
      CALL NEWPEN(IPE(K))
      CALL SCALE1(X,AX,N,M,IX,XMI,XMA,XC)
      CALL SCALE1(Y,AY,N,M,IY,YMI,YMA,YC)
      CALL PLOT(X(1),Y(1),3)
      IF(KU.GE.3)GC TC 20
      IF(KT.EQ.-1)GO TC 15
      YS=YS-H3
      CALL SYMBOL(XS,YS,H1,LK,0.,-1)
      CALL SYMBOL(999.C,999.0,H2,ISP,0.,2)
      IF(KT.EQ.4)CALL SYMBOL(999.,999.,H2,L4,C.,4*I4)
      IF(KT.EQ.5)CALL SYMBOL(999.,999.,H2,L5,0.,4*I5)
      IF(KT.EQ.6)CALL SYMBCL(999.,999.,H2,L6,0.,4*I6)
      IF(KT.GE.4)GO TC 15
      PC=FLOAT(N)
      CALL NUMBER(999.C,999.C,H2,PC,0.,-1)
      CALL SYMBOL(999.C,999.C,H2,IMP,0.,8)
      IF(KT.GT.0)GC TC 11
      CALL SYMBOL(999.C,999.0,H2,ISP,C.,2)
      CALL SYMBOL(999.C,999.0,H3,LT,0.,4*IT)
      CALL SYMBOL(XB,YB,H2,L4,0.,4*I4)
      CALL NUMBER(999.C,999.0,H2,V4,0.,3)
      CALL SYMBOL(XB,YB-H3,H2,L5,0.,4*I5)
      CALL NUMBER(999.C,999.0,H2,V5,C.,3)
      CALL SYMBOL(XB,YB-H3-H3,H2,L6,0.,4*I6)
      IF(KT.EQ.-2)CALL NUMBER(999.0,999.0,H2,V6,C.,3)
      GO TO 15
   11 CALL SYMBOL(999.C,999.C,H2,L4,0.,4*I4)
      CALL NUMBER(999.C,999.0,H2,V4,0.,3)
      IF(KT.EQ.1)GC TC 15
      CALL SYMBOL(999.C,999.0,H2,L5,0.,4*I5)
      CALL NUMBER(999.C,999.0,H2,V5,0.,3)
      IF(KT.EQ.2)GO TC 15
      CALL SYMBOL(999.0,999.0,H2,L6,0.,4*I6)
      CALL NUMBER(999.C,999.0,H2,V6,0.,3)
   15 IF(KU.LE.2)CALL SYMBOL(X(1),Y(1),H1,LK,0.,-1)
   20 DO 30 I=1,N
      IF(KU.GE.2)CALL PLOT(X(I),Y(I),2)
   30 IF(KU.LE.2)CALL SYMBCL(X(I),Y(I),H1,LK,0.,-1)
      IF(KU.NE.1)GO TC 50
      CALL SCALE1(U,AX,N,M,IX,XMI,XMA,XC)
```

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      CALL SCALE1(V,AY,N,M,IY,YMI,YMA,YC)
      CALL PLOT(U(1),V(1),3)
      DO 40 I=1,N
   40 CALL PLOT(U(I),V(I),2)
   50 K=K+1
      IF(K.GT.IP)K=2
      IF(IO.GT.1)GO TO 60
      CALL SYMBOL(X3,Y3,H4,L3,A3,4*I3)
      CALL NEWPEN(1)
      CALL AXIS(XO,YC,L1,-4*I1,AX, 0.,X(N+1),X(N+2),JX,KX)
      CALL AXIS(XO,YC,L2, 4*I2,AY,90.,Y(N+1),Y(N+2),JY,KY)
      CALL PLOT(XO+AX,YC,3)
      CALL PLOT(XO+AX,YO+AY,2)
      CALL PLOT(XO,YO+AY,2)
   60 IF(IO.EQ.1.OR.IO.EQ.2)RETURN
      CALL NEWPEN(0)
C     CALL PLOT(0.,0.,999)
      KEY=0
      RETURN
      END
C=======================================================================
      SUBROUTINE REGFAC(KUSC,SI1,NVS,GR,IFR,W,B,CS,NDI,VFR,FRC
     C,SK,CK,H,Y,V,C,S,NDW)
C--   REGRESSIONS FACILITY
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON KI5,KC3,IAP
      DIMENSION VFR(NDI),FRC(NDI),Y(NDI),V(NDI),CS( NDI),S( NDI)
     C,IFR(NDI),GR(NDI),B( NDI),C(NDI),H(NDI,NDI),SK(NDI),CK(NDI),W(NDI)
   41 WRITE(KC3,123)
      READ(KI5,105)K
      IF(K.LE.0)RETURN
      IF(K.LE.2.AND.KUSC.EQ.1)GO TO 96
      GO TO(81,82,83,84,85,86,41),K
   81 SSI=SI1*SI1
      DO 91 I=1,NVS
      GR(I)=IFR(I)
      W(I)=B(I)*SSI
   91 CS(I)=(GR(I)-32.)*.5555555555
      WRITE(12,124)(I,GR(I),B(I),CS(I),W(I),I=1,NVS)
      WRITE(KC3,124)(I,GR(I),B(I),CS(I),W(I),I=1,NVS)
      CALL BSTREG(6,NDI,CS,W,NVS,RA,VFR,FRC,SK,CK,GR,H,IPO,Y,V,SD,1,2)
      L=1
      M=2
      GO TO 31
   82 WRITE(12,125)(I,C(I),S(I),I=1,NDW)
      WRITE(KC3,125)(I,C(I),S(I),I=1,NDW)
      CALL BSTREG(6,NDI,C,S,NDW,RA,VFR,FRC,SK,QK,GR,H,IPO,Y,V,SD,2,1)
      L=2
      M=1
      GO TO 31
   83 L=1
      M=1
   99 WRITE(12,128)L,M,NDI
      WRITE(KC3,128)L,M,NDI
   95 WRITE(KC3,129)
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      READ(KI5,*)NPA
      IF(NPA.LT.3.OR.NPA.GT.NDI)GO TO 95
      DO 11 I=1,NPA
      WRITE(KC3,130)
   11 READ(KI5,*)W(I),CS(I)
      WRITE(12,126)(I,W(I),CS(I),I=1,NPA)
      WRITE(KC3,126)(I,W(I),CS(I),I=1,NPA)
   13 WRITE(KC3,135)
      READ(KI5,105)K
      IF(K.EQ.0)GO TO 15
      WRITE(KC3,136)
      READ(KI5,*)I,W(I),QS(I)
      WRITE(12,137)I,W(I),I,CS(I)
      GO TO 13
   15 CALL BSTREG(6,NDI,W,CS,NPA,RA,VFR,FRC,SK,QK,GR,H,IPC,Y,V,SD,L,M)
   31 WRITE(KC3,132)
      READ(KI5,105)K
      IF(K.EQ.0)GO TO 41
      WRITE(KC3,133)
      READ(KI5,*)XX
      IF(L.EQ.2.AND.XX.LE.0.)GO TO 31
      IF(L.EQ.1)VAL=FREG1(XX,RA,FRQ,NDI,IPO)
      IF(L.EQ.2)VAL=FREG1(DLOG(XX),RA,FRQ,NDI,IPO)
      IF(M.EQ.2)VAL=DEXP(VAL)
      WRITE(KC3,134)XX,VAL
      WRITE(12,134)XX,VAL
      GO TO 31
   44 WRITE(KC3,106)
      READ(KI5,105)K
      GO TO 41
   84 L=2
      M=1
      GO TO 99
   85 L=1
      M=2
      GO TO 99
   86 L=2
      M=2
      GO TO 99
   96 WRITE(KC3,127)K
      GO TO 41
  105 FORMAT(I1)
  106 FORMAT(/' >>>>------>     ( TO CONTINUE, ENTER 0  )')
  123 FORMAT(/' OPTIONS:'/
     &'        GO BACK TO MAIN MENU                        :  0'/
     &'        VISC=FUNC(TEMP.CELSIUS)                     :  1'/
     &'        F=FUNC(LN(R/F)) LAW FOR SMOOTH WALLS        :  2'/
     &'        Y=FUNC(X)        LAW TO TYPE ON TERMINAL    :  3'/
     &'        Y=FUNC(LN(X))    LAW TO TYPE ON TERMINAL    :  4'/
     &'    LN(Y)=FUNC(X)        LAW TO TYPE ON TERMINAL    :  5'/
     &'    LN(Y)=FUNC(LN(X))    LAW TO TYPE ON TERMINAL    :  6'/
     &' ENTER YOUR OPTION---I1')
  124 FORMAT(//' KINEMATIC VISCOSITY (SQ.MET./SEC., LN-SCALE)'/' AS A'
     &,' FUNCTION OF TEMPERATURE (CELSIUS)'/4X,'I',2(7X,'TEMP.'
     &,'    KIN.VISC.')/8X,'FARENHEIT    SQ.FT/SEC      CELSIUS    '
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     &,'SQ.MT/SEC'/(I5,2(F12.3,E12.3)))
 125  FORMAT(//' SMOOTH-WALL FRICTION COEFFICIENT FR'/' AS A FUNCTION'
     &,' OF REY/FR RATIO (LN-SCALE)'/ '     I  REYN./FRICT.  FR.COEFF.'
     &/(I5,E12.3,F12.3))
 126  FORMAT(//2(4X,'I',11X,'X',11X,'Y !')/(2(I5,2E12.5,' !')))
 127  FORMAT(/' AFTER ONE OF MAIN 3 TO 5 OPTIONS HAS BEEN USED,'/
     &' THIS SUB-OPTION',I2,' CANNOT BE USED <<====='//)
 128  FORMAT(/' 1) REGRESSION ANALYSIS WITH SCALES:'/I5,' FOR X'/I5
     &,' FOR Y'/' ( 1=NATURAL SCALE, 2=LOGARITHMIC SCALE )'/' FOR UP '
     &,' TO',I4,' DATA-PAIRS X,Y')
 129  FORMAT(' TO BE TYPED ON TERMINAL'//' ENTER NUMBER OF PAIRS----:')
 130  FORMAT(' ENTER A DATA-PAIR X,Y-----:')
 132  FORMAT(/' IF YOU LIKE TO GET A REGRESSION VALUE, ENTER 1'
     &       /' IF NOT,  ENTER 0 ----:')
 133  FORMAT(' ENTER "X" VALUE ------:')
 134  FORMAT(' FOR X =',F15.5,' ,  Y =',F20.9)
 135  FORMAT(/' IF YOU LIKE TO CHANGE SOME DATA, ENTER 1'
     &       /' IF NOT,  ENTER 0 ----:')
 136  FORMAT(' ENTER "I" ,"X(I)","Y(I)" VALUES----:')
 137  FORMAT(/' REPLACEMENT DONE: X(',I3,')=',F15.5,' , Y(',I3,')='
     &,F15.5)
      END
C=====================================================================
      SUBROUTINE STAT11(NCI,A,C,NNN,IP4,INUM,DVOL,MCL,VFR,FRQ,CL1,CL2
     &,X,S,IFR)
C=====>> STATISTICS (COMPUTE MEAN, STANDARD DEVIATION AND FREQUENCIES)
      IMPLICIT REAL*8 (A-H,O-Z)
C:::::   NEXT    1   LINES      NEEDED       FOR VS FORTRAN VERSION
      CHARACTER*4 IFR,A
      COMMON KI5,KO3,IAP
      DIMENSION IFR(NCI),VFR(NCI),FRQ(NCI),A(20),VOLT(32)
C-- THE PROGRAM HAD BEEN IMPLEMENTED FOR ONE CHANNEL ONLY
      IF(INUM.NE.1)RETURN
      READ(2,107)A
      X=0.
      XX=0.
      MCL=1+(CL2-CL1+C.0001)/DVOL
      DO 8 I=1,MCL
      VFR(I)=CL1+DVOL*I-DVOL
    8 FRQ(I)=0.
   12 CONTINUE
      I4=-IP4
      DO 19 I=1,4
      I4=I4+IP4
      IF(NNN.LT.IP4)IP4=NNN
      READ(2,108)(VOLT(J),J=1,IP4)
      DO 17 J=1,IP4
      X=X+VOLT(J)
      XX=XX+VOLT(J)*VOLT(J)
      JCL=(VOLT(J)-CL1+C.0001)/DVOL+1
      FRQ(JCL)=FRQ(JCL)+1.
   17 CONTINUE
      NNN=NNN-IP4
      IF(NNN.LE.0)GO TO 20
   19 CONTINUE
```

```
      GO TO 12
   20 DO 22 I=1,MCL
   22 FRQ(I)=FRQ(I)/C
      X=X/C
      S=DSQRT(DABS(XX-X*X*C)/(C-1.))
      WRITE(12,106)C,X,S
      WRITE(KO3,106)C,X,S
      WRITE(KO3,110)
      READ(KI5,112)K
      FM=0.
      DO 32 I=1,MCL
   32 IF(FRQ(I).GT.FM)FM=FRQ(I)
      GM=50./FM
      HM=C/GM
      WRITE(12,111)MCL,FM,HM
      WRITE(KO3,111)MCL,FM,HM
      SUM=0.
      DO 40 I=1,MCL
      IN=FRQ(I)*GM
      SUM=SUM+FRQ(I)
      IF(IN.EQ.0)GO TO 36
      DO 35 J=1,IN
   35 IFR(J)='!'
   36 IN1=IN+1
      IF(IN1.GE.50)GO TO 38
      DO 37 J=IN1,49
   37 IFR(J)=' '
      IFR(50)='!'
   38 WRITE(12,113)I,VFR(I),FRQ(I),(IFR(J),J=1,50)
   40 WRITE(KO3,113)I,VFR(I),FRQ(I),(IFR(J),J=1,50)
      WRITE(12,114)SUM
      WRITE(KO3,114)SUM
      RETURN
C-- FORMATS:
  106 FORMAT(/F9.0,'-SAMPLES MEAN:        XM=',F10.3
     &       /' SAMPLE STANDARD DEVIATION:  SM=',F10.3/)
  107 FORMAT(20A4)
  108 FORMAT(32F8.3)
  109 FORMAT(8F9.3)
  110 FORMAT(/' TO CONTINUE, PRESS  < RETURN >  KEY  ')
  111 FORMAT(/' THE',I4,' FREQUENCIES OBTAINED :'/
     &/' NUM   VALUE      FREQ                  GRAPH ( FROM 0.0 TO',F5.2
     &,' )'/30X,' ( SCALE IS    ! =',F8.1,' SAMPLES )'/)
  112 FORMAT(I1)
  113 FORMAT(I4,F8.3,F10.5,'   !',50A1)
  114 FORMAT(15X,7('=')/8X,' SUM =',F8.5)
      END
C======================================================================
      SUBROUTINE STATI2(NCI,MCL,VFR,FRQ,SK,CK,D,DV,FME,FMO)
C=====>> STATISTICS ( COMPUTE SKEWNNESS AND KURTOSIS )
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON KI5,KO3,IAP
      DIMENSION A(5),VMO(4),VFR(NCI),FRQ(NCI)
      DATA VMX/99999.999D0/
C-- INITIALIZATION
```

```
      DO 2 I=1,4
    2 VMO(I)=0.
      FI=.0
      S1=0.
      IE=0
C-- LOOP ON SAMPLES
      DO 10 I=1,MCL
      IF(IE.EQ.1)GO TO 4
C-- MEDIAN
      S0=S1
      S1=S1+FRQ(I)
      IF(S1.LT..5)GO TO 4
      IF(S1.NE.S0)FME=VFR(I-1)+(.5-S0)*(VFR(I)-VFR(I-1))/(S1-S0)
      IF(S1.EQ.S0)FME=VFR(I)
      IE=1
    4 A(1)=FRQ(I)
C-- MODE
      IF(FRQ(I).LT.FI)GO TO 5
      FI=FRQ(I)
      IM=I
C-- MOMENTS ABOUT THE ORIGIN
    5 DO 10 J=2,5
      A(J)=A(J-1)*VFR(I)
   10 VMO(J-1)=VMO(J-1)+A(J)
      FMO=VFR(IM)
      H=D*D
C-- MOMENTS ABOUT THE MEAN
      X=VMO(1)-D
      S=VMO(2)-H
      T=VMO(3)-3.*D*VMO(2)+2.*H*D
      F=VMO(4)-4.*D*VMO(3)+(6.*VMO(2)-3.*H)*H
C-- SHEPPARD'S CORRECTIONS
      V=DV*DV
      SC=S-V/12.
      IF(SC.LE.0.)SC=S
      IF(SC.LE.0)GO TO 35
C-- SKEWNESS AND KURTOSIS
      TS=T/SC
      FS=FC/SC
      FC=F-(S*.5-.0291667*V)*V
      B1=TS*TS/SC
      B2=FS/SC
      G1=DSQRT(DABS(B1))
      G2=B2-3.
      SK=.5*DABS(G1*(B2+3.)/(5.*B2-6.*B1-9.))
      IF(FME-D)26,22,24
   22 IF(FMO-D)26,26,24
   24 SK=-SK
   26 CK=G2
      XM=VMO(1)
   35 SD=DSQRT(DABS(SC))
C-- PRINT RESULTS
      IF(DABS(SK).GT.VMX)SK=VMX
      IF(DABS(CK).GT.VMX)CK=VMX
      WRITE(K03,101)XM,SD,FME,FMO,SK,CK
```

```
      WRITE(KC3,102)(VMC(I),I=1,4),X,S,SC,T,F,FC,B1,B2,G1,G2
      WRITE(12,101)XM,SD,FME,FMO,SK,CK
      WRITE(12,102)(VMC(I),I=1,4),X,S,SC,T,F,FC,B1,B2,G1,G2
      RETURN
C-- FORMATS:
 101  FORMAT(/' VALUES FOUND THROUGH THE CURVE OF FREQUENCIES:'
     &/'              MEAN     =',F10.3/' STANDARD DEVIATION =',F10.3
     &/'             MEDIAN    =',F10.3/'             MODE     =',F10.3
     &/'            SKEWNESS   =',F10.3/'          KURTOSIS   =',F10.3)
 102  FORMAT(/' MOMENTS ABOUT THE ORIGIN AT ZERO:'/
     &16X,'FIRST    =',F12.6/16X,'SECOND   =',F12.6/
     &16X,'THIRD    =',F12.6/16X,'FOURTH   =',F12.6/
     &      ' MOMENTS ABOUT THE MEAN (AND SHEPARD CORRECTIONS) :'/
     &16X,'FIRST    =',F12.6/16X,'SECOND   =',F12.6,
     &10X,'CORRECT.=',F12.6/16X,'THIRD    =',F12.6/
     &16X,'FOURTH   =',F12.6,10X,'CORRECT.=',F12.6/
     &            ' COEFFICIENT BETA AND GAMMA:'/
     &16X,'BETA 1   =',F12.6,10X,'BETA 2   =',F12.6/
     &16X,'GAMMA 1  =',F12.6,10X,'GAMMA 2  =',F12.6)
      END
C=====================================================================
      SUBROUTINE ESTREG(NMX,NDI,Y,S,N,A,B,C,E,F,G,H,IPO,Z,U,SC,IL1,IL2)
C         FOR THE OBTENTION OF A BEST REGRESSION
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION U(NDI),S(NDI),E(NDI),F(NDI),Y(NDI),Z(NDI)
     &,B(NDI),C(NDI),G(NDI),H(NDI,NDI)
C-- OPTIONAL CHANGES IN SCALES
      NMAX=MIN0(N-2,NMX)
      SD=1.D10
      IPO=0
      GO TO(18,22),IL1
  18  DO 21 J=1,N
  21  Z(J)=Y(J)
      GO TO 25
  22  DO 24 J=1,N
  24  Z(J)=DLOG(Y(J))
  25  GO TO(26,28),IL2
  26  DO 27 J=1,N
  27  U(J)=S(J)
      GO TO 31
  28  DO 30 J=1,N
  30  U(J)=DLOG(S(J))
C-- GET REGRESSIONS AND SELECT THE BEST ONE ( SMALLEST SD )
  31  WRITE(12,42)
  42  FORMAT(/' 2) OBTENTION OF BEST REGRESSION'/)
      DO 51 I=1,NMAX
      SDE=REGRE1(N,Z,U,I,AL,B,NDI,NDI,NDI,NDI,E,F,G,H,0,1.D-12)
      IF(SDE.EQ.0.)WRITE(12,48)I
      IF(SDE.GT.0.)WRITE(12,47)I,SDE
  47  FORMAT(I5,'-ORDER REGRESSION:         SD=',F15.7)
  48  FORMAT(I5,'-ORDER REGRESSION:         N O T    F O U N D')
      IF(SDE.GE.SD.OR.SDE.LE.0.01)GO TO 51
      DO 49 J=1,I
  49  C(J)=B(J)
      A=AL
```

```
      SD=SDE
      IPO=I
   51 CONTINUE
      IF(IPO.EQ.0)GO TO 60
   53 WRITE(12,56)N,IPO,A,(C(K),K=1,IPO)
      RETURN
   56 FORMAT(/' FOR',I5,' POINTS, BEST REGRESSION FOUND IS OF ORDER',I5
     &/' INTERCEPTION COEFFICIENT :   A =',F15.7/
     &' REGRESSION COEFFICIENTS  :    B =',3E15.7/(33X,3E15.7))
   60 WRITE(12,66)
   66 FORMAT(/' NO REGRESSION WAS FOUND '/)
      RETURN
      END
C=======================================================================
      FUNCTION FREG1(X,A,B,M,N)
C    COMPUTE THE REGRESSION VALUE FROM THE REGRESSION POLYNOMIAL
C        B= REGRESSION COEFICIENTS  !  M= B DIMENSION
C        N= POLYNOMIAL ORDER        !  FREG1= REGRESSION VALUE (RETURN)
C-----------------------------------------------------------------------
      REAL*8 X,A,B,FREG1,F
      DIMENSION B(M)
      IF(N.EQ.1)GO TO 2
      K=N-1
      F=B(N)
      DO 1 I=1,K
      J=N-I
    1 F=X*F+B(J)
      FREG1=F*X+A
      RETURN
    2 FREG1=A+B(1)*X
      RETURN
      END
C=======================================================================
      FUNCTION REGRE1(M,X,Y,N,A,B,N1,N2,N3,N4,SX,SYX,CYX,C,KW,EPS)
C    NTH-ORDER POLYNOMIAL REGRESSION ON M DATA POINTS IN X,Y ARRAYS
C-- ARG: M= NUMBER OF DATA POINTS      !  X= BASE POINTS
C        N= POLYNOMIAL ORDER           !  Y= POLICMIAL VALUES AT X
C        A= REGRESSION INTERCEPT COEFF.!  B= REGRESSION COEFFICIENTS
C        SX= SUMS OF XY VALUES         !  CYX= VECTOR OF "INECP." TERMS
C        SYX= SUMS OF XI*Y VALUES      !
C        C= AUGMENTED MATRIX OF COEFF. !  KW= PRINTER DEVICE (IF=/0)
C        EPS= TOLERANCE FOR SIMUL ROUT.!  N1,N2,N3,N4= ARRAY DIMENSIONS
C   REGRE1 RETURNS STANDARD ERROR OF ESTIMATE S  (= 0. IF EPS NOT SAT'D)
C-----------------------------------------------------------------------
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION C(N1,N1),SX(N2),SYX(N3),CYX(N3),X(N4),Y(N4),B(N3)
      DATA IK/0/,K3/12/
C-- CHECK DIMENSIONS
      IF(KW.NE.0)K3=KW
      IK=IK+1
      REGRE1=0.
      IF(N1.GT.N.AND.N2.GE.N+N.AND.N3.GE.N.AND.N4.GE.M.AND.M.GT.N)GOTO 9
      WRITE(K3,204)IK,M,N,N1,N2,N3,N4
      RETURN
C-- COMPUTE SUMS OF POWERS AND PRODUCTS
```

```
    9  NTW=N+N
       NP1=N+1
       SY=0.
       SYY=0.
       DO 1 I=1,N
       NPI=N+I
       SX(I)=0.
       SX(NPI)=0.
    1  SYX(I)=0.
       DO 3 I=1,M
       SY=SY+Y(I)
       SYY=SYY+Y(I)*Y(I)
       DUM=1.
       DO 2 J=1,N
       DUM=DUM*X(I)
       SX(J)=SX(J)+DUM
    2  SYX(J)=SYX(J)+Y(I)*DUM
       DO 3 J=NP1,NTW
       DUM=DUM*X(I)
    3  SX(J)=SX(J)+DUM
C-- COMPUTE COEFFICIENTS C(I,J)
       FM=M
       CYY=SYY-SY*SY/FM
       DO 4 I=1,N
       CYX(I)=SYX(I)-SY*SX(I)/FM
       C(I,NP1)=CYX(I)
       DO 4 J=1,N
       IPJ=I+J
    4  C(I,J)=SX(IPJ)-SX(I)*SX(J)/FM
       IF(N.EQ.1)GO TO 6
C-- CALL ON SIMUL TO SOLVE SIMULTANEOUS EQUATIONS (IF N>1 )
       DET= SIMUL(N,C,B,EPS,1,N1,N3)
       IF(KW.GT.0)WRITE(KW,200)DET
       IF(DET.NE.0.)GO TO 6
       REGRE1=0.
       RETURN
C-- COMPUTE INTERCEPT A AND STANDARD ERROR S
    6  DUM=SY
       TEM=CYY
       IF(N.EQ.1)B(1)=C(1,2)/C(1,1)
       DO 7 I=1,N
       DUM=DUM-B(I)*SX(I)
    7  TEM=TEM-B(I)*CYX(I)
       A=DUM/FM
       DEN=FLOAT(M-N-1)
       IF(DEN.EQ.0.)RETURN
       S=DSQRT(DABS(TEM)/DEN)
       IF(TEM.LT.0.)WRITE(K3,205)IK,TEM
       REGRE1=S
       IF(KW.GT.0)WRITE(KW,202)A,S,N,(B(I),I=1,N)
       RETURN
C-- FORMATS
  200  FORMAT(/' FROM REGRE1(SIMUL): DET=',1PE12.4,' <=====-***')
  202  FORMAT(/5('='),' POLYNOMIAL REGRESSION ANALYSIS BY REGRE1 ROUTINE'
     &,' ',30('=')/' INTERCEPT COEFF. A=',F12.5,' , STANDARD ERROR     '
```

```
     &, 'S=',F12.5/' THE',I3,' REGRESSION COEFFICIENTS ARE:'/(1P4E15.7))
 204  FORMAT(/' WARNING: ON THE',I5,' CALL ON TO REGRE1, SOME OF THE '
     &/'VALUES M,N,N1,N2,N3,N4=',6I5,' WERE FOUND INCORRECT'/)
 205  FORMAT(/' WARNING: ON THE',I5/' CALL ON TO REGRE1, STANDARD DEVIA'
     &,'TION IS MISTAKENLY COMPUTED'/' CAUSE TEM=',E12.3/)
      END
C=========================================================================
      FUNCTION SIMUL(N,A,X,EPS,IND,NRA,NRX)
C    GAUSS-JORDAN REDUC'N & INVERSE MATRIX USING MAXIMUM PIVOT STRATEGY
C-- ARG: N= NUMBER OF UNKNOWNS           !  A= MATRIX OF COEFF'S  (N*N)
C        X= VECTOR OF UNKNOWNS           !  EPS= MAXIMUM ALLOWED PIVOT
C        NRA,NRX=DIMENSIONS OF A AND X !  IND= SWITCH ACC. TO :
C   IF IND= 0, VECT. OF COEFF'S IN COL. N+1 OF A (INVERSE RETURNED IN A)
C   IF IND> 0, SAME EXCEPT INVERSE IS NOT COMPUTED
C   SIMUL ALWAYS RETURNS DETERMINANT OF A (N*N) (= 0. IF EPS NOT SAT'D)
C-------------------------------------------------------------------------
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 SIMUL
      DIMENSION IRO(40),JCO(40),JOR(40),Y(40),A(NRA,NRA),X(NRX)
C-- INITIALIZATION
      MAX=N
      IF(IND.GE.0)MAX=N+1
      IF(N.LE.40.AND.N.LT.NRA.AND.N.LE.NRX)GO TO 5
      WRITE(12,200)N,NRA,NRX
      SIMUL=0.
      RETURN
C-- BEGIN ELIMINATION
    5 DET=1.
      DO 18 K=1,N
      KM1=K-1
C-- SEARCH FOR PIVOT
      PIV=0.
      DO 11 I=1,N
      DO 11 J=1,N
C-- SCAN IRO & JCO ARRAYS FOR INVALID PIVOT SUBSCRIPTS
      IF(K.EQ.1)GO TO 9
      DO 8 ISC=1,KM1
      DO 8 JSC=1,KM1
      IF(I.EQ.IRO(ISC))GO TO 11
      IF(J.EQ.JCO(JSC))GO TO 11
    8 CONTINUE
    9 IF(DABS(A(I,J)).LE.DABS(PIV))GO TO 11
      PIV=A(I,J)
      IRO(K)=I
      JCO(K)=J
   11 CONTINUE
C-- CHECK PIVOT
      IF(DABS(PIV).GT.EPS)GO TO 13
      SIMUL=0.
      RETURN
C-- UPDATE DETERMINANT
   13 IRK=IRO(K)
      JCK=JCO(K)
      DET=DET*PIV
C-- NORMALIZE PIVOT ROW ELEMENTS
```

```
      DO 14 J=1,MAX
   14 A(IRK,J)=A(IRK,J)/PIV
C-- CARRY OUT ELIMINATION AND DEVELOP INVERSE
      A(IRK,JCK)=1./PIV
      DO 18 I=1,N
      AIJ=A(I,JCK)
      IF(I.EQ.IRK)GO TO 18
      A(I,JCK)=-AIJ/PIV
      DO 17 J=1,MAX
   17 IF(J.NE.JCK)A(I,J)=A(I,J)-AIJ*A(IRK,J)
   18 CONTINUE
C-- ORDER SOLUTION VALUES (IF ANY)
      DO 20 I=1,N
      IRI=IRO(I)
      JCI=JCO(I)
      JOR(IRI)=JCI
   20 IF(IND.GE.0)X(JCI)=A(IRI,MAX)
C-- SIGN OF DETERM'T
      INT=0
      NM1=N-1
      DO 22 I=1,NM1
      IP1=I+1
      DO 22 J=IP1,N
      IF(JOR(J).GE.JOR(I))GO TO 22
      JTE=JOR(J)
      JOR(J)=JOR(I)
      JOR(I)=JTE
      INT=INT+1
   22 CONTINUE
      IF(INT/2*2.NE.INT)DET=-DET
C-- IF IND > 0 RETURN WITH RESULTS
      IF(IND.LE.0)GO TO 26
      SIMUL=DET
      RETURN
C-- IF IND =< 0 UNSCRAMBLE THE INVERSE
   26 DO 28 J=1,N
      DO 27 I=1,N
      IRI=IRO(I)
      JCI=JCO(I)
   27 Y(JCI)=A(IRI,J)
      DO 28 I=1,N
   28 A(I,J)=Y(I)
      DO 30 I=1,N
      DO 29 J=1,N
      IRJ=IRO(J)
      JCJ=JCO(J)
   29 Y(IRJ)=A(I,JCJ)
      DO 30 J=1,N
   30 A(I,J)=Y(J)
C-- RETURN FOR IND =< 0
      SIMUL=DET
      RETURN
  200 FORMAT(/' SIMUL CANNOT OPERATE CAUSE N=',I3,'>90.OR.N>NRA=',I3
     &,'.OR.N>=NRX=',I3/)
      END
```

```
C=====================================================================
      SUBROUTINE GAUSS1(GA,WG,NU,NUW)
C   GAUSSIAN ABSCISAES AND WEIGTHS ( FROM NUW= 1  TO  NUW= 10 )
      IMPLICIT REAL*8 (A-H,O-Z)
      DIMENSION GA(NU),WG(NU),A(5,9),C(5,9)
C-- ABSCISAE VALUES MATRIX
      DATA A/.5773502691,4*0.
     &      ,.7745966692,4*0.
     &      ,.8611363115,.3399810435,3*0.
     &      ,.9061798459,.5384693101,3*0.
     &      ,.9324695142,.6612093864,.2386191860,0.,0.
     &      ,.9491079123,.7415311855,.4058451513,0.,0.
     &      ,.9602898564,.7966664774,.5255324099,.1834346424,0.
     &      ,.9681602395,.8360311073,.6133714327,.3242534234,0.
     &      ,.9739065285,.8650633666,.6794095682,.4333953941,.1488743389/
C-- COEFFICIENTS VALUES MATRIX
      DATA C/2.,4*0.
     &      ,.5555555556,.8888888889,3*0.
     &      ,.3478548451,.6521451548,3*0.
     &      ,.2369268850,.4786286704,.5688888889,0.,0.
     &      ,.1713244923,.3607615730,.4679139435,0.,0.
     &      ,.1294849661,.2797053914,.3818300505,.4179591836,0.
     &      ,.1012285362,.2223810344,.3137066458,.3626837833,0.
     &      ,.0812743883,.1806481606,.2606106964,.3123470770,.3302393550
     &      ,.0666713443,.1494513491,.2190863625,.2692667193,.2955242247/
C---------------------------------------------------------------------
C-- CHECK CONSISTENCY
      IF(NUW.GT.NU.OR.NUW.LT.1.OR.NU.LT.1.OR.NU.GT.10)STOP
C-- CARRY OUT PROCEDURE
      IF(NUW.GT.1)GO TO 2
      GA(1)=0.
      WG(1)=2.
      RETURN
    2 N=NUW-1
      K=NUW/2
      DO 4 I=1,K
      J=NUW-I+1
      GA(I)=-A(I,N)
      GA(J)=+A(I,N)
      WG(I)=C(I,N)
    4 WG(J)=WG(I)
C-- IF ORDER EVEN, RETURN
      GO TO(8,8,5,8,5,8,5,8,5,8),NUW
C-- IF ORDER ODD, COMPUTE MIDDLE POINT
    5 GA(K+1)=0.
      WG(K+1)=C(K+1,N)
    8 RETURN
      END
C=====================================================================
      SUBROUTINE ANLOGO(A,CSAMP,NNO,IP4C,INUM,MINU,NSEC,CL1,CL2)
C:::::   THIS SUBROUTINE        NEEDED        FOR VS FORTRAN VERSION
C   REPLACE FOR SAME ROUTINE IN FILE "ANLOGO FORTRAN A" WRITTEN FOR
C                  MODCOM FORTRAN IV VERSION
      CHARACTER*4 A
      COMMON KI5,KC3,IAP
```

```
      DIMENSION A(20)
      QSAMP=0
      RETURN
      END
```

```
C=====================================================================
      SUBROUTINE ANLOGO(A,QSAMP,NNO,IP40,INUM,MINU,NSEC,CL1,CL2)
C=====>>      FOR THE INPUT OF RANDOM ANALOG SIGNALS
C     PROGRAMMED BY ?? AT USDA SEDIMENTATION LABORATORY
C     MODIFIED BY ADEFF               ---> LAST UPDATING: AUG/10/86 <---
C---------------------------------------------------------------------
      REAL*8 A,QSAMP,CL1,CL2
      DIMENSION TIME(2),A(20),VOLT(32)
      DIMENSION ITABL(13)
      INTEGER*4 MTCMOD
      INTEGER*2 ITABLE(16),IVOLT(256),UFTOUT(10),UFTTTY(10)
     'INTEGER*2 I1,JJJ,IXX,IEOF,IC,IP,IBT,LP
      INTEGER*2 IVALU(16)
      INTEGER *2 NAME(4),STATUS,INUMX,FFF
      EQUIVALENCE (ITABL(6),ITABLE)
      DATA ITABLE/16*0/,ITABL/13*0/
      DATA NAME/"MO","DL",Z0040,0/
      DATA UFTOUT/0,ZAF00,ZA000,0,0,0,Z4000,0,0,0/
      DATA UFTTTY/0,ZC800,ZA000,0,0,0,Z4000,0,0,0/
      ICHECK=0
      IEOF=0
      NS=0
      ISTAT=0
      I1 = 0
      JJJ= 0
      FFF=0
    1 FORMAT(I5)
      WRITE(3,12)
   12 FORMAT(' IF YOU WISH OLD HEADING, PRESS ¢ RETURN !'
     &      /'            ....NEW HEADING, ENTER 1 -----:')
      I=0
      READ(5,1)I
      IF(I.EQ.0)GO TO 13
      WRITE(3,8)
    8 FORMAT(' ENTER DATA HEADING (UP TO 80 CHARACTERS)----:')
      READ(5,9) A
   13 WRITE(2,9) A
    9 FORMAT(20A4)
      WRITE(3,2)
    2 FORMAT(' ENTER THE NO. OF SAMPLES ( IN THOUSANDS )----:')
      READ(5,*) ANN
      NNN=ANN*1000
      QSAMP=NNN
      IF(NNN.LE.0)RETURN
C     WRITE(3,3)
C   3 FORMAT(' ENTER THE NO. OF CHANNELS-----:')
C     READ(5,*) INUM
C--- PREVIOUS 3 CARDS REPLACED BY NEXT ONE:
      INUM=1
```

```
      INUMX=INUM+1
      IP=(32/INUM)*INUM*4
      IBT=IP*2
      I1=0
C     WRITE(3,5)
C   5 FORMAT(' ENTER SEC. FOR DELAY- 100 = 1 SEC.------:')
C     READ(5,*) JJJ
C--- PREVIOUS 3 CARDS REPLACED BY NEXT ONE:
      JJJ=1
      MINU=I1
      NSEC=JJJ
C     WRITE(3,6)
C   6 FORMAT(' ENTER CHANNEL LIST TO BE SAMPLED (16 INTEGER VALUES)---')
C     READ(5,*) (ITABLE(J),J=1,INUM)
C--- PREVIOUS 3 CARDS REPLACED BY NEXT TWO:
      ITABLE(1)=7
      ITABLE(2)=14
      WRITE(3,11)
   11 FORMAT(' W A I T ...( ENTER "E" TO STOP COLLECTING DATA )  ')
C     THE FOLLOWING SETS A TERMINATION READ FOR SAMPLING.
      INLINE
      LDI,2 UFTTTY
      LDI,8 #8000
      LDI,14 ICHECK
      LDI,15 2
      REX,#32
      FINI
      IA=0
      CALL MTCMOD(NAME,STATUS)
      CALL PIOINI(NAME,STATUS)
      CALL TIMER(TIME(1))
      DO 40 JKL= 1,NNN
      DO 10 II = 1,16
   10 IVALU(II)=0
      CALL SCANI(NAME,STATUS,IVALU,ITABLE,INUMX,FFF)
      DO 20 I=1,INUM
      IA=IA+1
      IVOLT(IA)=IVALU(I)
   20 CONTINUE
C     THE FOLLOWING SETS THE TIME DELAY BETWEEN SAMPLES.
      INLINE
      LDI,8 #14
      LDM,14 I1
      OBR,14,0
      LDM,15 JJJ
      REX,#32
      NOP
      FINI
   30 CONTINUE
      LP=IP
      IF(JKL.EQ.NNN)  LP=IA
      IF(IA-(IA/LP)*LP.NE.0) GO TO 40
      NS=JKL
      IC=0
      IF(IA.GT.IP) IC=IP
C     THE FOLLOWING DOES A QUICK RETURN WRITE OF DATA TO OUT.
C     AT THIS POINT THE DATA ARE IN MULTIPLES OF 5 MILIVOLTS.
      INLINE
      LDI,2 UFTOUT
      LDI,14 IVOLT
      ADM,14 IC
      LDI,15 IBT
      LDI,8 #8001
      REX,#32
      FINI
```

```
      IF(ICHECK.NE.0) GO TO 41
      IF(IA.EQ.IBT) IA=0
   40 CONTINUE
   41 CALL TIMER(TIME(2))
      TIME(1)=TIME(1)
      TIME(2)=TIME(2)
      WRITE(3,45) TIME(1),TIME(2)
   45 FORMAT(' INITIAL TIME: ',F20.5,'; FINAL TIME',F20.5)
      TIME(1)=TIME(2)-TIME(1)
      DO 47 J=3,6,3
   47 WRITE(J,48) TIME(1)
   48 FORMAT(/' ELAPSED TIME', F20.5,' SECONDS')
C     THE FOLLOWING WRITES END OF FILE AND REWINDS FILE OUT.
      INLINE
      LDI,2 UFTOUT
      LDI,8 #0007
      REX,#32
      LDI,8 #0002
      REX,#32
      FINI
      IF(NNN.GT.NS) NNN=NS
      WRITE(3,53) NNN
      QSAMP=NNN
      NNN=NNN*INUM
      NNO=NNN
      IP4=IP/4
      IP40=IP4
   52 CONTINUE
   53 FORMAT('  NO. OF SAMPLES =',I7/10X,'W A I T ........')
C     THE FOLLOWING READS FILE "OUT".
      INLINE
      LDI,2 UFTOUT
      LDI,8 #0000
      LDI,14 IVOLT
      LDI,15 IBT
      REX,#32
      FINI
      DO 59 I=1,4
      I4=(I-1)*IP4
      IF(NNN.LT.IP4) IP4=NNN
      DO 57 J=1,IP4
      VOLT(J)=IVOLT(J+I4)
      VOLT(J)=VOLT(J)*.0003125
      IF(VOLT(J).GT.CL2)CL2=VOLT(J)
      IF(VOLT(J).LT.CL1)CL1=VOLT(J)
   57 CONTINUE
      WRITE(2,58) (VOLT(J),J=1,IP4)
      NNN=NNN-IP4
      IF(NNN.LE.0) GO TO 60
   59 CONTINUE
      GO TO 52
   58 FORMAT(32F8.3)
   60 END FILE 2
C     THE FOLLOWING DELETE ANY READ KEYED TO TRM AND REWIND FILE "OUT".
      INLINE
      LDI,2 UFTTTY
      LDI,8 #9
      REX,#32
      LDI,2 UFTOUT
      LDI,8 #0002
      REX,#32
      FINI
      RETURN
      END
```

APPENDIX B

Operating System's Execution Files

B.1: MODOMP's procedure using Hewllet-Packard plotter:

```
$PRODEFAULT VELMEAS

$JOB

$SFM AUX1 A

$SFM AUX2 B

$SFM %1 C

$SFM AUX3 D

$ASS 1 A 2 B 3 TO 5 TI 12 D 14 C

$EXE LAB X
```

B.2: <u>IBM/VM-CMS's execution file using Tektronix plotters</u>

```
*=====================================================================
&CONTROL ERROR OFF NOMSG
CLRSCRN
*   PLAB EXEC  ( VERSION BY S.E.ADEFF ) --> LAST UPDATING: NOV/10/86 <--
*   EXEC TO DECLARE ALL GLOBAL TXTLIBS NEEDED, AND EXECUTE  THE VELMEAS
*   CALCOMP PLOT PROGRAM TO BE PLOTTED ON TEKTRONIX PLOTTER
*   (PROGRAM OBJECT CODE IS LAB TEXT A)
&SPACE
&IF .&1 NE . &IF &1 NE ? &IF .&2 NE . &IF &2 NE ? &GOTO -START
&BEGTYPE
USAGE: <EXEC> PLAB &1 &2

        WHERE &1 IS THE FILETYPE OF THE FILE "FN14" CONTAINING
        THE RESULTS OF STATISTICAL ANALYSES FOR A VELOCITY PROFILE:

                    FN14 &1 A

        AND &2 IS THE FILETYPE OF THE FILE "FN12" CONTAINING
        THE RESULTS OF COMPUTATIONS

                    FN12 &2 A

&END
&EXIT &RETCODE
-START
*INPUT FILES DEFINITION
FI 1  DISK LAB P1 A1    (LRECL 80 BLOCK 80 RECFM F PERM
FI 2  DISK LAB P2 A1    (LRECL 80 BLOCK 80 RECFM F PERM
FI 6 TERM               (LRECL 80 BLOCK 80 RECFM F PERM
FI 12 DISK FN12 &2 A1   (LRECL 80 BLOCK 80 RECFM F PERM
FI 14 DISK FN14 &1 A1   (LRECL 80 BLOCK 80 RECFM F PERM
*---------------------------------------------------------------------
GLOBAL TXTLIB VLNKMLIB CMSLIB VFORTLIB CALPREPL UTIL CALCOMP
LOAD LAB (CLEAR NOMAP
&IF &RETCODE NE 0 &GOTO -ERR2
&TYPE ======== ======== PLAB EXEC. ======== ========
&TIME RESET
&TIME TYPE
START *
&TIME TYPE
&TYPE ======== ======== END OF RUN ======== ========
&EXIT
-ERR2 &TYPE ERROR LOADING PROGRAM
&EXIT &RETCODE
```

B.3: IBM's execution file using Versatec plotter

```
*=========================================================================
&CONTROL OFF NOMSG
CLRSCRN
*   VLAB EXEC  ( VERSION BY S.E.ADEFF ) --> LAST UPDATING: NOV/10/86 <--
*   EXEC TO DECLARE ALL GLOBAL TXTLIBS NEEDED, AND EXECUTE  THE VELMEAS
*   CALCOMP PLOT PROGRAM TO BE PLOTTED ON VERSATEC PLOTTER
*   (PROGRAM OBJECT CODE IS LAB TEXT A)
&SPACE
&IF .&1 NE . &IF &1 NE ? &IF .&2 NE . &IF &2 NE ? &GOTO -START
&BEGTYPE
USAGE: <EXEC> VLAB &1 &2

        WHERE &1 IS THE FILETYPE OF THE FILE "FN14" CONTAINING
        THE RESULTS OF STATISTICAL ANALYSES FOR A VELOCITY PROFILE:

                    FN14 &1 A

        AND &2 IS THE FILETYPE OF THE FILE "FN12" CONTAINING
        THE RESULTS OF COMPUTATIONS

                    FN12 &2 A

&END
&EXIT &RETCODE
-START
*INPUT FILES DEFINITION
FI 1  DISK LAB P1 A1     (LRECL 80 BLOCK 80 RECFM F PERM
FI 2  DISK LAB P2 A1     (LRECL 80 BLOCK 80 RECFM F PERM
FI 6 TERM                (LRECL 80 BLOCK 80 RECFM F PERM
FI 12 DISK FN12 &2 A1    (LRECL 80 BLOCK 80 RECFM F PERM
FI 14 DISK FN14 &1 A1    (LRECL 80 BLOCK 80 RECFM F PERM
*------------------------------------------------------------------------

&FN = LAB
&FT = TEXT
STATE &FN &FT A
&IF &RETCODE EQ 0 &SKIP 2
    &TYPE *** FILE: &FN &FT A NOT FOUND ***
    &EXIT &RETCODE
FILEDEF PLOTPARM DISK PLOTPARM DATA * (PERM)
FILEDEF PLOTLOG DISK PLOTLOGA DATA A4 (PERM)
FILEDEF VECTR1 DISK VECTR1 DATA A4 (PERM)
FILEDEF VECTR2 DISK VECTR2 DATA A4 (PERM XTENT 65535 BLKSIZE 4092)
GLOBAL TXTLIB VLNKMLIB CMSLIB VALTLIB VFORTLIB PLOTLIB
&IF &RETCODE EQ 0 &SKIP 2
    &TYPE *** MISSING TXTLIBS ***
    &EXIT &RETCODE
CLRSCRN
LOAD &FN (START NOMAP CLEAR NODUP
FILEDEF PLOTLOG CLEAR
FILEDEF VECTR1  CLEAR
FILEDEF VECTR2  CLEAR
FILEDEF PLOTPARM CLEAR
FILEDEF PLOTLOG DISK PLOTLOGB DATA A4
FILEDEF VECTR1 DISK VECTR1 DATA A4
```

```
FILEDEF VECTR2 DISK VECTR2 DATA A4 (XTENT 65535)
CP SP PUN RSCS
CP TAG DEV PUN VERSATEC
-L100
&BEGTYPE
DO YOU WANT PLOT OR STOP? (PLOT,<ENTER>)
     PLOT   - SENDS OUTPUT DIRECTLY TO THE PLOTTER,  THEN ERASES
              ALL VERSATEC WORK FILES AND THEN EXITS.
  <ENTER> - ERASES ALL VERSATEC WORK FILES AND AND THEN EXITS.
&END
&READ VARS &WHERE
&IF .&WHERE EQ .PLOT &GOTO -FIN
&IF .&WHERE EQ . &GOTO -L500
&TYPE ..... INVALID RESPONSE!!!
&TYPE
&TYPE
&GOTO -L100
&EXIT
-FIN
&IF .&WHERE EQ .DISK &GOTO -L200
&IF .&WHERE EQ .PLOT &GOTO -L300
&GOTO -L100
-L200
FILEDEF RJERASTR DISK &FN DATA A4 (RECFM FB BLKSIZE 80 LRECL 80)
&GOTO -L400
-L300
&TYPE ..... W A I T    FOR THE PROCESS TO FINISH.
FILEDEF RJERASTR PUNCH (RECFM FB BLKSIZE 80 LRECL 80)
-L400
VTPLOT
&IF .&WHERE NE .DISK &GOTO -L450
PUN &FN DATA
&BEGTYPE
DO YOU WANT TO ERASE YOUR OUTPUT FILE - &FN DATA ? (DEFAULT = YES)
&END
&READ VARS &ANS
&IF .&ANS = .YES ERASE &FN DATA A
-L450
ERASE PLOTLOGB DATA A4
-L500
ERASE VECTR1 DATA A4
ERASE VECTR2 DATA A4
ERASE PLOTLOGA DATA A4
CP SP PUN OFF
&EXIT &RETCODE
```

APPENDIX C

Operator's Form used

Experiment No. [ ] Date: [/ /86] Experimenter: ____________________

I. Discharge and Uniform Flow Establishment

A. Bleed discharge water manometer and lines (1)
B. Check zero of discharge manometer (1)
C. Start Pump. Date: [/ /86] time [ ] (1)

D. Set water to desired nominal depth [inches]
E. Adjust pump to desired nominal ΔH [in. Hg]

F. Adjust flume slope until $\Delta_{ch} = \Delta_w$ (2)
Enter final values obtained:
Flume: H_{ch} [ft] H_w [ft] H_w [ft]
L_{ch} [ft] L_w [ft] L_w [ft]
Δ_{ch} [ft] Δ_w [ft] Δ_w [ft]

Enter counter register [ ]

Compute slope $S_{ch} = \Delta_{ch}/20.$, $S_w = \Delta_w/20.$

S_{ch} = [ ] , S_w = [ ]

G. Read depth y_t = [inches] [inches]

H. Read discharge manometer: H [in. Hg] H [in.Hg]
L [in. Hg] L [in.Hg]
$H + L = \Delta H$ [in. Hg] ΔH [in.Hg]

Compute $Q = 0.17946 \sqrt{\Delta H}$ = [ft^3/sec]

I. Read water temperature: [ ]

NOTES: (1) If pump is off
(2) Use auxilary paper form
(Allow for oscillations to disappear)

II. Velocity Profile Measurements

A. Check for bubbles and eliminate them
B. Check zero and span on velocity meter
zero control setting [ ]
Span control setting [ ]
C. Clear probe tip of trash or bubbles
D. Measure u(y) using the gauge for: (3)

Gauge	y(mm)	Mean	Gauge	y(mm)	Mean
50	1.55	[ ]	39	12.55	[ ]
49.8	1.75	[ ]	37	14.55	[ ]
49.6	1.95	[ ]	35	16.55	[ ]
49.4	2.15	[ ]	33	18.55	[ ]
49.2	2.35	[ ]	31	20.55	[ ]
49	2.55	[ ]	(4)		
48.7	2.85	[ ]	26	25.55	[ ]
48.5	3.05	[ ]	21	30.55	[ ]
48.2	3.35	[ ]	16	35.55	[ ]
48	3.55	[ ]	11	40.55	[ ]
47.6	3.95	[ ]	6	45.55	[ ]
47.3	4.25	[ ]			
47	4.55	[ ]	31	50.55	[ ]
46.6	4.95	[ ]	26	55.55	[ ]
46.3	5.25	[ ]	21	60.55	[ ]
46	5.55	[ ]	16	65.55	[ ]
45.6	5.95	[ ]	11	70.55	[ ]
45.3	6.25	[ ]	6	75.55	[ ]
45	6.55	[ ]	1	80.55	[ ]
44.5	7.05	[ ]			
44	7.55	[ ]			
43.5	8.05	[ ]	Values on File SEA		
43	8.55	[ ]			
42.5	9.05	[ ]			
42	9.55	[ ]			
41	10.55	[ ]	Start Read	[:]	
40	11.55	[ ]	End Read	[:]	

NOTES: (3) Enter mean after "beep" and before "RETURN"
(4) Move probe with compensator

APPENDIX D

Data for wall-correction procedure

This Appendix contains information used by the Program VELMEAS during the wall-correction procedure. This information was transcribed from the operator's form of Appendix C. The units used are those of the respective instrumental employed in its acquisition. Equivalent values in the International System of Units (SI) are to be found in table 3.1.

The following notes refer to observations in Table succeeding.

(1): Original smooth bed of steel sheet.

(2): Smoother painted steel sheet

(3): Lost measurements because damage in Analog-to-digital signal converter.

(4): Horizontal velocity profile measurements. The position y is given in mm. in each of two levels corresponding to same flow conditions.

(5): Same as in (4)

(6): Same as in (4)

(7): Rough bed formed by laying a packed layer of lead balls.

(8): Lost measurements due to troubles during operation.

(9): These are part of a same profile. Later unified in file sea6036.

(10): Conditions in the upper stilling basin too rough (Discharge too high).

(11): These are part of a same profile. Later unified in file sea6067.

Survey of data required for wall-correction procedure

Experiment number (filename)	Temperature T Celsius D.	Depth y_t in.	Disch.Manom. ΔH Hg.in.	Slope S	Observations
1 to 9					(1) (3)
10 to 12					(2) (3)
13 (sea6001)	22.0	2.05	6.35	0.00115	(2) (3)
14 (sea6002)	21.0	2.34	8.20	0.00105	(2) (3)
15 (sea6003)	27.0	2.28	8.10	0.00125	(2) (3)
16 (sea6004)	28.0	2.51	10.00	0.001025	(2) (3)
17 (sea6005)	28.2	2.45	9.95	0.00115	(2)
18 (sea6006)	27.5	2.49	10.05	0.00110	(2)
19 (sea6007)	23.5	2.51	12.00	0.00120	(2)
20 (sea6008)	24.5	2.49	12.05	0.00140	(2)
21 (sea6009)	26.0	2.42	7.95	0.00100	(2)
22 (sea6022)	26.8	2.39	7.99	0.00105	(2)
23 (sea6023)	26.8	2.16	5.95	0.00100	(2)
24 (sea6024)	26.6	2.14	5.97	0.00110	(2)
25 (sea6025)	25.6	2.16	4.02	0.00075	(2)
26 (sea6026)	26.2	2.14	3.97	0.00075	(2)
27 (sea6027)	21.2	2.41	8.23	0.00100	(2) (4) y=12.2
28 (sea6028)	28.4	2.40	8.25	0.00100	(2) (4) y=49.0
29 (sea6029)	27.4	2.13	3.87	0.00085	(2) (5) y=10.82
30 (sea6030)	25.7	2.13	3.87	0.00085	(2) (5) y=43.28

Survey of data required for wall-correction procedure (continued)

Experiment number (filename)	Temperature T Celsius D.	Depth y_t in.	Disch.Manom. ΔH Hg.in.	Slope S	Observations
31 (sea6031)	26.2	2.29	12.02	0.00155	(2) (6) y=11.63
32 (sea6032)	21.8	2.29	12.00	0.00175	(2) (6) y=46.53
33 (sea6033)	28.9	2.49	5.40	0.00165	(7) (8)
34 (sea6034)	30.0	2.49	5.50	0.00165	(7)
35 (sea6035)	30.75	2.53	5.65	0.00150	(7)
36 (sea6036)	25.25	2.485	2.00	0.00045	(7) (9)
37 (sea6037)	25.25	2.485	2.00	0.00045	(7) (9)
38 (sea6038)	29.5	2.48	2.00	0.00045	(7)
39 (sea6039)	30.0	2.48	4.00	0.00100	(7)
40 (sea6040)	30.0	2.47	4.00	0.00110	(7)
41 (sea6041)	29.0	2.52	8.00	?	(7) (8)
42 (sea6042)	29.95	2.54	8.00	0.00210	(7) (8)
43 (sea6043)	28.0	2.515	8.00	0.00205	(7)
44 (sea6044)	29.4	2.515	8.00	0.00205	(7)
45 (sea6045)	29.75	2.505	10.00	0.00260	(7)
46 (sea6046)	29.9	2.495	10.00	0.00250	(7)
47 (sea6047)	28.95	2.505	12.00	0.00295	(7)
48 (sea6048)	30.0	2.505	12.00	0.00300	(7)
49 (sea6049)	30.1	2.55	14.00	0.00335	(7)
50 (sea6050)	30.95	2.555	14.00	0.00330	(7)

Survey of data required for wall-correction procedure (continued)

Experiment number (filename)	Temperature T Celsius D.	Depth y_t in.	Disch.Manom. ΔH Hg.in.	Slope S	Observations
51 (sea6051)	30.05	2.545	16.00	0.003775	(7) (10)
52 (sea6052)	31.0	2.545	16.00	0.003775	(7) (10)
53 (sea6053)	29.9	2.48	2.00	0.00050	(7)
54 (sea6054)	29.9	2.51	2.00	0.000475	(7)
55 (sea6055)	30.2	2.51	4.00	0.00095	(7)
56 (sea6056)	30.45	2.505	4.00	0.00095	(7)
57 (sea6057)	28.5	2.51	6.00	0.001575	(7)
58 (sea6058)	31.0	2.50	6.00	0.00160	(7)
59 (sea6059)	31.0	2.51	8.00	0.002025	(7)
60 (sea6060)	31.0	2.520	8.00	0.00200	(7) (8)
61 (sea6061)	30.95	2.49	8.00	0.00205	(7)
62 (sea6062)	29.6	2.48	10.00	0.00265	(7) (8)
63 (sea6063)	30.1	2.485	10.00	0.002575	(7)
64 (sea6064)	29.0	2.51	12.00	0.00295	(7)
65 (sea6065)	30.55	2.505	12.00	0.00300	(7)
66 (sea6066)	31.0	2.495	14.00	0.00335	(7)
67 (sea6067)	30.55	2.51	14.00	0.003375	(7) (11)
68 (sea6068)	30.55	2.51	14.00	0.003375	(7) (11)
69 (sea6069)	30.75	2.53	16.00	0.00380	(7)
70 (sea6070)	29.25	2.53	16.00	0.00385	(7)